The TREND IN ENGINEERING

at the University of Washington

In this issue:

WATER VAPOR TRANSMISSION THROUGH BUILDING MATERIALS

CORRELATION AND EXTRAPOLATION METHODS FOR CREEP DATA

PATTERN RECOGNITION IN AN ELECTRONIC READER

MOLECULAR ASSOCIATION IN THE VAPOR PHASE SYSTEM ACETIC ACID, ETHYL ALCOHOL, ETHYL ACETATE, AND WATER

HIGHWAY RESEARCH CONTRACTS

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THE ENGINEERING EXPERIMENT STATION

THE ENGINEERING EXPERIMENT STATION of the University of Washington, which was established in December, 1917, performs a three-fold function:

1) It stimulates, promotes, and coordinates investigations and research in all fields of engineering.
2) It publishes results of significant research achievements.
3) It provides opportunities through Graduate Research Assistantships for engineering students to extend their professional education while pursuing a course of study leading to the M.S. or Ph.D. degree.

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OUR SPOON-FED STUDENTS AND THEIR NEEDS

THE TERM "SPOON-FED STUDENTS" appearing recently in educational criticism suggests not only an infantile manner of receiving "food" but also the insipid type of pabulum likely to be administered in this manner. In a school system guilty of spoon-feeding, all students must suffer, but the superior percentage is most seriously affected.

Foreign students are particularly critical of the lack of responsibility imposed on our college students. Recently a delegate of the Foreign Student Leadership Project from the Sudan, declared in an interview that university students in the United States are so concerned with getting good grades that they do not have time to learn. He was, moreover, accustomed to a grading and testing system which stressed original thought instead of memorizing, and quoted the opening remark of one of his United States professors as, "I give the grades on what I say and the book says, not on what you think."

Actually, "American or European plan" applies to higher education as well as to hotels. English and European universities are, essentially, postgraduate institutions devoted to specialized training. Our students who go abroad for graduate study must often compete with foreign graduates who are more advanced by at least two years. Most of our colleges and universities are extensions of our secondary schools, defined, often, by law and designed to meet the requirements of the average high school graduate. With the increasing number of young people who attend high school and are permitted to graduate, the average level of attainment has tended to become lower, yet it is questionable whether the state universities would be allowed to raise their requirement sufficiently to reject a larger percentage of high school graduates than in the past. It is doubtful, also, that such a step is desirable.

If we must offer higher education to nearly everyone, are there ways of improving our educational facilities for the superior student?

The advantages of the honors system were pointed out fifteen years ago by Frank Aydelotte, former president of Swarthmore College which has perhaps gone as far as any institution in this country in giving its superior students great freedom and responsibility in developing their intellectual powers.[1] He maintained that we can obliterate, at least partially, the distinction between vocational and liberal studies and that "This is strikingly true in such a subject as engineering, where the brilliant student can dispense with a great many detailed technical applications of scientific knowedge because his very power of reasoning enables him to apply fundamental principles to detailed situations." He suggested that the time thus saved be devoted to broadening the student's education. One of the features Aydelotte most strongly recommended was to employ outside examiners to conduct the intermediate and final examinations and to grade candidates for degrees. He reminded us that this system tests both students and their professors as well. The late Dean Edwin R. Guthrie of the University of Washington commented on the desirable rapport set up between student and teacher when they work together to prepare for an examination.[2]

Criticism of our "course system" has come from many sources. Clarence H. Faust, vice-president of the Ford Foundation and president of the Fund for the Advancement of Education, deplores the tendency to consider a course "as almost the only instrument of education, and indeed as the essence of education." The course "must run through a quarter, or semester, or year, a specified number of hours a week in order to be readily recorded . . . as a step in the education of students." He quotes a vice-president of the University of Chicago as saying that the best thing that happened to the academic program at Chicago in the 1940's was the necessity of pruning some four hundred courses from the curriculum.[3] Emeritus Professor G. Safford Torrey, of the University of Connecticut, has urged that we "give our students the ability to outgrow teachers and courses and learn for themselves," and a professor of electrical engineering, in discussing the "course mechanism," has declared, "The student is apt to lean so heavily upon this mechanism that he has no idea how to proceed when no courses are available to him."[4]

Aside from the rigidity of course requirements that usually make no allowance for differences in student levels and needs, far too many electives of little or no educational value clutter up our college curricula and offer the indifferent student an easy way to make credits. Even student editorials in various parts of the country have suggested replacing such courses as "family relations" and "hotel management" with advanced academic or technical courses which are now crowded out.

Dr. Guthrie pointed out another form of spoon-feeding which perhaps has not received enough attention. He wrote: "The extension of elementary teaching methods into the state universities is still in progress. The change is reflected in college textbooks, which no longed pretend to be contributions to knowledge or the work of active scholars and scientists in the field, but are prepared by the collaboration of writers and illustrators. A successful college text is now big business and royalties run into many thousand a year. To get widespread adoption, publishers and authors must, as in the elementary schools for many years, see to it that the text is easy and clear; that it will raise no controversial issues in the field; that it will not take sides on any controversy over theory; that it will be acceptable to all minorities and to all political and religious factions capable of making themselves felt."

This dilution of substance may not be as evident in engineering texts as in those of some other fields, but the average student, concerned chiefly with making a grade or passing a course is invariably tempted to choose the easiest readings. He is not likely, either, to find another of Dr. Guthrie's remarks very palatable: "The American system has its face sternly set against at least one freedom, the freedom to fail. It is quite possible that this freedom is essential if students are to be led to assume responsibility for their own progress.[2]

Recognizing the necessity of providing flexible programs for the superior percentage, a number of first-rank institutions, including some state universities, have already initiated or are initiating a full-fledged honors system for the junior and senior years. The students who are accepted (and requirements are usually rigorous) attend classes or not, at will, work in small seminar groups, or under a partial or complete tutorial plan, and are examined by authorities other than the professors under whom they have studied.

But the primary function of universities—especially state universities—is to help each individual to realize his greatest potentiality. The spoon-feeding characteristic of the course-and-hour system may underestimate the need of even

1 *Breaking the Academic Lockstep*, Harper & Bros., N. Y. and London, 1944.

2 *The State University: Its Function and Its Future*, University of Washington Press, 1959.

3 "Rising Enrollments and Effective Use of Faculty Resources," *Bulletin, American Conference of Academic Deans*, Vol. XLIII, No. 2.

4 "The Practicing Engineer Views the New Curriculum-Styling of the Engineering College," by Edmund D. Ayres, *News in Engineering at the Ohio State University*, Nov. 1958.

the average student for more responsibility and greater independence. His tendency to conform without question and to accept the status quo when it represents the line of least resistance was shown recently when the majority of a history class agreed that Socrates was justly condemned to death "because he upset people."

Dr. Faust, previously quoted, said that one of his most depressing observations, when a college dean, was the development in freshman students of "precisely the wrong kind of sophistication about college work." He had noticed during orientation week their obvious eagerness and delight at the prospect of a new educational experience, but by the end of the academic year, although socially satisfied, they had found that campus intellectual life did not really differ from their earlier years in school. They had sat in classes, read assignments, noted lectures, and recited. They had taken tests and acquired credits. But their progress toward a bachelor's degree differed little from promotion from one grade to the next.[1]

We may even guess that, once "settled down" they quickly resumed the whole pattern of their secondary school values, alarmingly illustrated by Dean Guthrie's report of interviews with selected high school applicants for scholarships. The "school activities" in which they had been engaged seemed to represent the chief impact which their high school education had made upon them, and the lists of these activities were awe-inspiring. To be sure, their grades were very high, since most of them came from the top five per cent of the graduating class, but few manifested any interest or enthusiasm connected with academic studies. When asked whether they had read any book outside of class assignments during the preceding year, some were indignant that they could have been *expected* to do so in view of their activity programs.[2] American students have extraordinary individual freedom in managing their self-government councils, their extracurricular activities, and indeed most aspects of their personal lives, but are deprived of the opportunity for taking responsibility for their intellectual development. Thus we can naturally expect them to focus their attention and interest on those spheres in which they are permitted to develop their own skills.

If, as Dean Guthrie remarked, "a large fraction of university teaching is well designed to kill off any undue interest on the part of the student in the subject matter," more ways must be found to demonstrate the attractions of the intellectual life, not only to the highly gifted but to the bulk of our college population whose influence will be felt in our government offices and who will bring up a large part of our next generation.

There need be no attempt to prod the student of limited ability into undertaking studies which he is unable to master or even become interested in. Sometimes, however, the apathetic student just has not been tempted with the right lure. While many colleges and universities may not be able to attract and retain a large number of outstanding teachers, even brief contacts with famous "imports" may stimulate student interest to a surprising extent. The program of the Walker-Ames professors at the University of Washington is such an attempt on a small scale. Several eminent authorities in different fields are usually appointed for each quarter to give advanced courses or lectures. Each is sponsored by a department of the University. One especially successful venture was the engagement in the fall of 1947-1948 of Dr. Cornelius Lanczos, Hungarian mathematician and friend of Einstein, who delivered a series of ten lectures on the Fourier Series and its applications. Thinking that very few students (or professors, either) would be interested in this subject, the committee on arrangements reserved a small classroom for the lectures After the first lecture Dr. Lanczos and his audience had to move to a large amphitheatre lecture room. At the last lecture, even the aisles were filled with eager listeners, many of whom, though unable to follow all the speaker's mathematical formulas, were fascinated by his philosophical approach and dynamic personality.

The Visiting Scholar Program set up by Phi Beta Kappa in 1956 was so enthusiastically received that the Society had to refuse over 25 per cent of the 1958 requests for speakers. During three years seventeen speakers paid a total of 149 visits to institutions requesting this service, each Scholar remaining for at least two days and holding group discussions and informal classes as well as giving one major address.[3]

Following the visit of Henry Margenau, physicist and "natural philosopher," to Reed College in 1958, the student newspaper reported:

"At this point freshmen are asking the upper classmen about quantum mechanics, the pol and sociology majors are vowing to take physics; and the philosophers and physicists are thinking over the new approaches they have been exposed to . . . . Everyone has been given . . . an approach rather than a subject matter . . . . He set all of us thinking —and that is what made him unique and important."

Through the Richmond Area University Center, thirteen Virginia institutions now share visits from lecturers of great distinction who may visit some or all of the campuses without too great a financial burden on the individual college. The Center has made many research grants and established cooperative professorships.

A similar program on a much greater scale could perhaps be initiated by groups of industries who have shown more than token interest in furthering engineering education. Lecturers need not even be confined to scientists and engineers. After all, industrial management has long been urging a broader, more liberal education for its future employees.

The present picture also has its encouraging aspects. Fears that American students will not accept greater responsibility and higher standards have been at least partially dispelled by student support of suggestions to introduce accelerated courses and the honors system. Yes, some among this generation of university students are becoming increasingly articulate in their demand for better fare—for something they can get their teeth into.

The president of the U . S. National Student Association declared, "Too often we wait for catastrophe or crisis to shape our educational policy," and, after urging such remedial steps as recruiting teachers, increasing salaries, making college curricula more effective and expanding educational opportunities, he insisted, "We do not wish to be coddled but even less do we want our education dictated by fear of the Kremlin."[4] Newly aroused student interest in foreign languages can be measured by the greatly increased enrollment in language courses. Perhaps we can hope that a new and more admirable style for "conformity" may be adopted.

Meanwhile, among the thousands of college freshmen this fall, many will be looking forward to a "new educational experience." Since first impressions are often the most lasting, learning should be made to appear in its most impressive and appealing light from the *beginning* of a student's college experience. Moreover, since learning comes through doing, not through being told, each student, whatever his level, should be given as much responsibility as he can handle in setting his own pace, and some opportunity, if possible, to satisfy his urge to explore, while he is still at the "eager age."

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1 *Op. cit.*
2 *Op. cit.*
3 *Key Reporter*, April, 1959.
4 *School and Society*, Feb. 15, 1958.

July, 1959

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IN ENGINEERING

at the University of Washington

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CONTENTS

Our Spoon-Fed Students and Their Needs 1

Water Vapor Transmission Through Building Materials
Howard E. Collicott, Harold M. Hendrickson . . . 5

Correlation and Extrapolation Methods of Creep Data
Mario Pio Gomez 9

Pattern Recognition in an Electronic Reader
Philip M. Pahl, David L. Johnson 16

Molecular Association in the Vapor Phase System Acetic Acid, Ethyl Alcohol, Ethyl Acetate, and Water
Lyndon R. Babcock, Jr., L. N. Johanson 22

Highway Research Contracts *Robert G. Hennes* . . . 28

Hill Appointed Associate Dean of Engineering 32

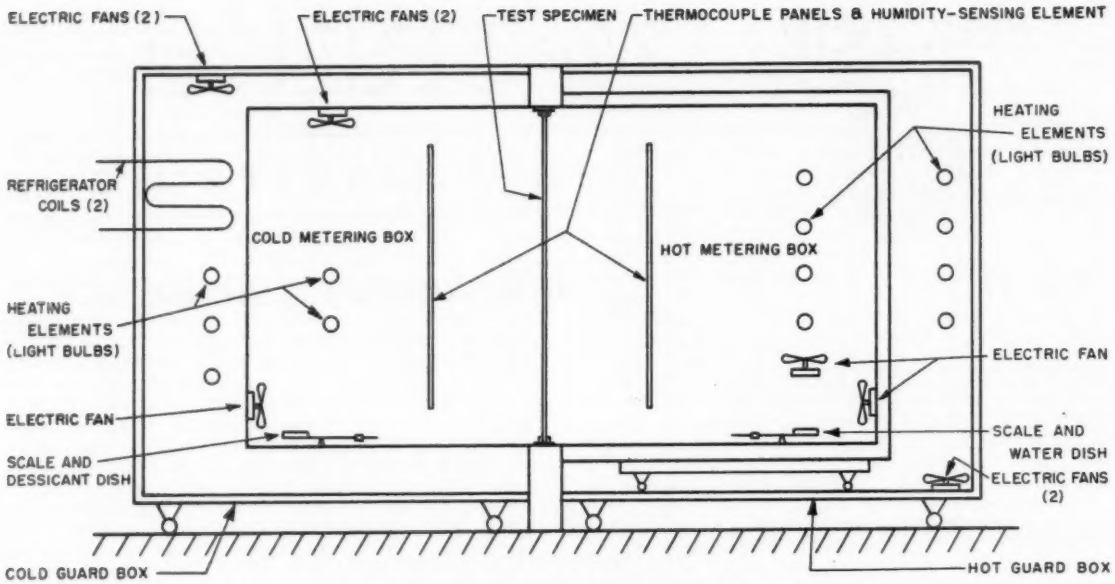


FIG. 1. DIAGRAM OF GUARDED HOT BOX

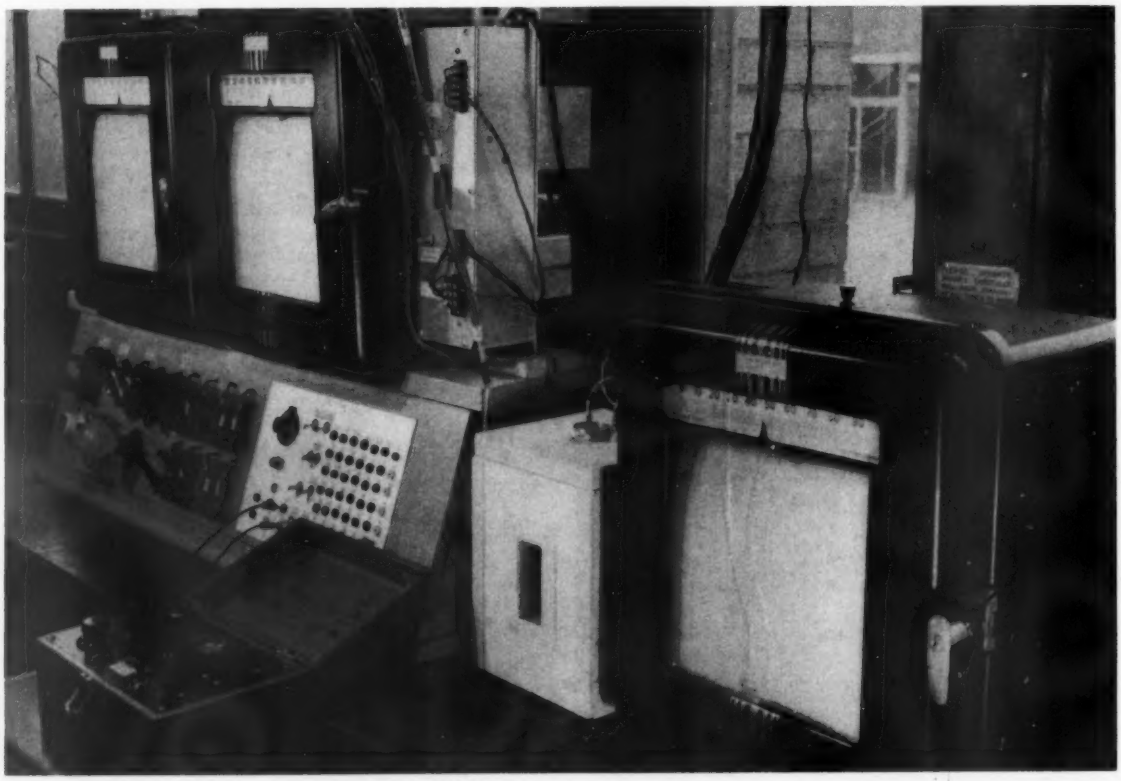


FIG. 2. INSTRUMENTATION CONTROL PANEL

Water Vapor Transmission Through Building Materials

HOWARD E. COLLICOTT
Research Assistant
Engineering Experiment Station

HAROLD M. HENDRICKSON
Professor of Mechanical Engineering

H. E. Collicott

In the United States the standard method of measuring water vapor transmission through building materials in sheet form is by either the "wet-cup" (water) or the "dry-cup" (desiccant) method, in accordance with American Society for Testing Materials (ASTM) designation C355-54T or E96-53T. In either method, the specimen to be tested is made into a cover, about 10 in. by 10 in. for the dish or cup. In the "wet-cup" method, water is placed in the dish; in the "dry-cup" method, desiccant is used. Inside the dish the relative humidity is assumed to be 100 per cent or 0 per cent, while the outside ambient conditions are maintained at 50 per cent relative humidity ± 2 per cent and between 70° F and 90° F temperature ± 1 degree. The dishes rest on scales so that the gain or loss of moisture during a given interval of time can be measured. One disadvantage of the ASTM methods is that the "dry cup" results do not agree with the "wet cup" results.

Description of Test Facility

This paper describes a more versatile facility for measuring water vapor transmission with various temperatures and humidities on the two sides of the test specimen. The base unit was a guarded hot box constructed essentially in accordance with ASTM designation C236-54T. The inside metering hot box was vapor-proofed by lining it with 22-gage galvanized sheet metal. An inside metering cold box was fabricated of the same material, and the specimen was clamped between the open ends of the two inner boxes. The outer hot and cold guard boxes were placed around the inner boxes as shown in Fig. 1.

Five copper-constantan thermocouples in series were installed in both the hot and cold metering boxes. The thermocouples were connected to Leeds and Northrup Micromax recorders, modified to function as relay control units, one for each metering box. (See Fig. 2.) Any variation from a given voltage would cause the Micromax to actuate a relay which controlled the heating elements. A third Micromax relay unit controlled the hot guard box temperature, but this Micromax was connected to sense the difference in voltage between five copper-constantan thermocouples on the inside surface of the hot metering box and five on the outside surface. The hot guard box temperature was thus controlled so as to maintain a zero temperature gradient across the walls of the hot metering box. No attempt was made to control the temperature accurately in the cold guard box which was cooled by refrigeration to a temperature somewhat below that desired in the cold metering box, thus tending to overcool the sheet-metal metering box. The exact inside temperature was controlled by the Micromax relay unit operating the heating elements. An El-Tronics humidity-sensing element was installed in each metering box. This was a unit whose electrical resistance varied with relative humidity. A calibration curve of resistance versus relative humidity was supplied by the manufacturer. The suggested control circuit was modified, as in Fig. 3, for better sensitivity. A change in resistance of the humidity-sensing element changed the bias on the tube, thereby changing the plate current. A sensitive relay was provided to actuate between the limits of 0.70- to 0.72-milliampere plate current to control the relative humidity within ± 1 per cent. This relay then operated a second relay, which in turn controlled the fans directed at the two flat dishes on the scales, one containing water and the other anhydrous calcium chloride desiccant. (See Figs. 4 and 5.) The units were calibrated by using a resistance box, simulating the sensing element, in conjunction with the manufacturer's calibration curve. The resistance of the box was set to correspond to a value obtained from the calibration curve of resistance versus relative humidity as supplied with the elements, and the resulting humidity control setting required to produce a plate current of 0.71 milliampere was recorded.

H. M. Hendrickson

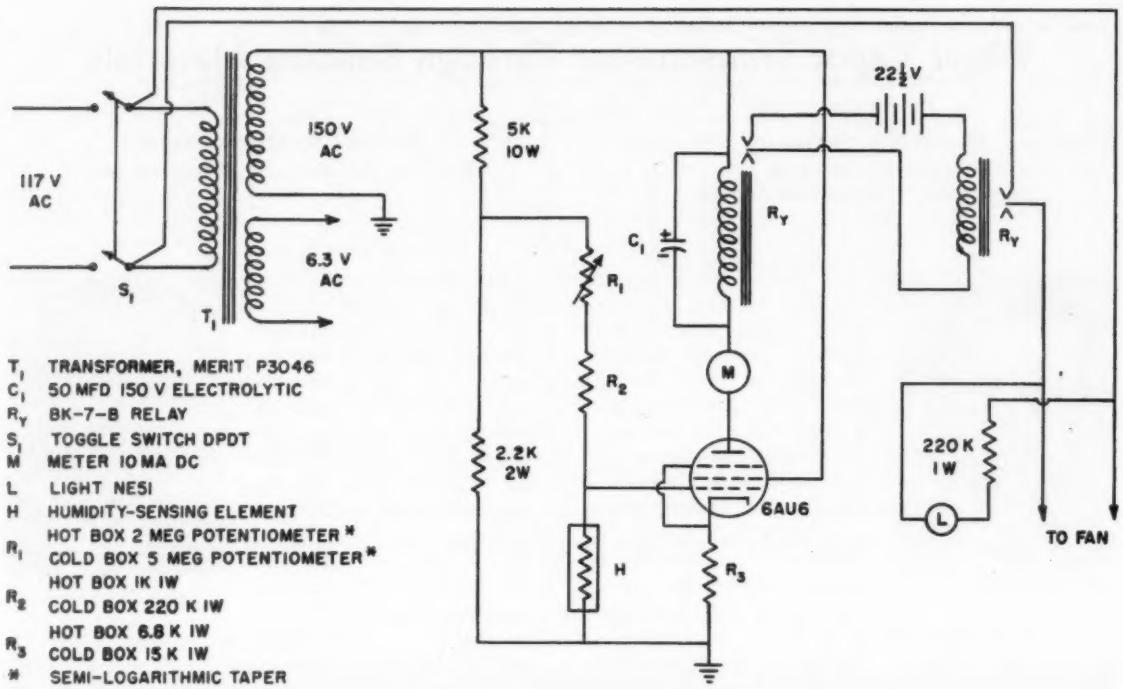


FIG. 3. HUMIDITY-CONTROL WIRING DIAGRAM

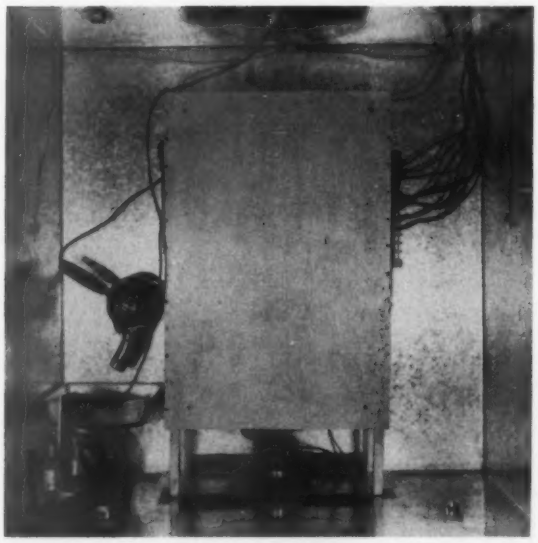


FIG. 4. HOT METERING BOX INSTRUMENTATION
(Thermocouple panel removed)

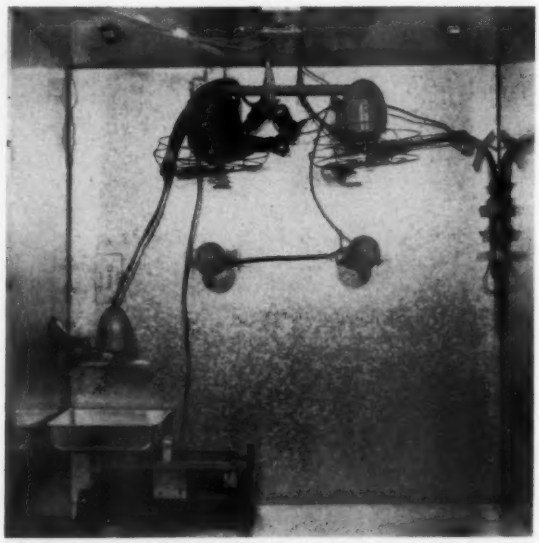


FIG. 5. COLD METERING BOX INSTRUMENTATION
(Thermocouple panel removed)

By repeating this procedure, a curve of humidity-control setting versus relative humidity was obtained for each element and control unit.

The loss of water from the hot metering box and the gain in weight of the desiccant in the cold metering box were measured with a scale and strain-gage arrangement which may be seen in Figs. 4 and 5. The flat dish rested on the pan of the scale, the standard weights on the scale arm absorbing the dead weight of the dish and contents, and the weight change was measured by a Statham model YE-48-600 open-wire strain gage attached to the scale arm. The changes in the strain gage due to weight changes were measured with a Baldwin SR-4 type M strain indicator. Calibration of the units, using standard weights, showed a linear relation between SR-4 indicator readings and weight added to the scale for the range of weights used in these tests. From this type of calibration the scale constants for the two Statham gages were found to be 2.845 grains per unit and 2.657 grains per unit for the hot and cold metering box scales, respectively. The humidity and weight-control units are shown in Fig. 6.

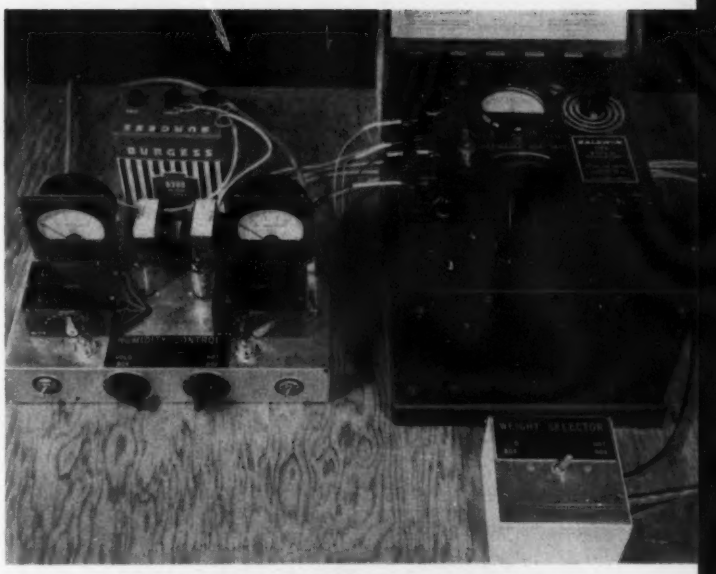


FIG. 6. HUMIDITY- AND WEIGHT-CONTROL UNITS

Theoretical Discussion

The theory of water vapor transmission through building materials is complicated because many materials are hygroscopic and because the assumptions of steady flow and a diffusion process are not always valid. Therefore, test results vary greatly, and the conditions of the test should always be stated. Water vapor will pass through a wall if there is a vapor pressure gradient across it, just as heat will flow through a wall if there is a temperature gradient across it. Water vapor transmission calculations are usually based on Fick's law which is closely analogous to Fourier's equation for heat flow, assuming steady-state conditions.

$$\frac{G}{\theta} = AM\Delta p = A\frac{\mu}{x}\Delta p, \text{ from Fick's Law,} \quad (1)$$

$$\frac{Q}{\theta} = AC\Delta t = A\frac{k}{x}\Delta t, \text{ from Fourier's Eq.} \quad (2)$$

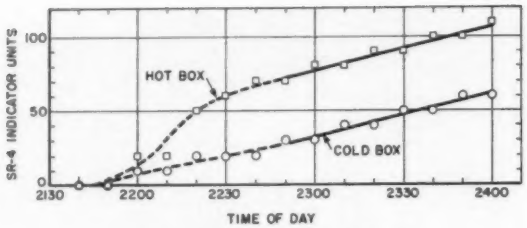
where

G = vapor transmission (grains)
M = permeance (grains/hr ft² in. Hg) or (perms)
μ = permeability (grains in./hr ft² in. Hg) or (perm-in.)
θ = time (hr)
Δp = vapor pressure difference (in. Hg)
A = area (ft²)
x = thickness (in.)
Q = heat flow (Btu)
C = conductance (Btu/hr ft² deg F)
k = conductivity (Btu in./hr ft² deg F)
Δt = temperature difference (deg F)

Using Eqs. 1 and 2 and the fact that resistance to flow is the reciprocal of the conductance or permeance, we can also calculate the temperature and vapor-pressure gradients through a composite wall of different materials. If the temperature at any point in the wall falls below the dewpoint as determined by the vapor pressure at that point, condensation will occur and trouble is likely to be encountered.

Test Procedure

The apparatus was started up and the controls set for the desired temperatures and humidities in the hot and cold metering boxes on either side of the specimen. The initial strain-gage readings were recorded. When the test temperatures and relative humidities stabilized, another set of strain-gage readings to be used as a zero reference for weight, was recorded. Strain-gage readings indicating the decrease in weight of water on the scale on the hot side and the increase in weight of the desiccant on the scale on the cold side were then taken at regular time intervals for several hours, depending upon the permeance of the specimen. (Low permeance materials should be tested for longer periods than high permeance materials.) The strain-gage readings were plotted against time, and were continued until the points plotted in a straight line, indicating that steady-flow conditions prevailed. (See Figs. 7 and 8.) If condensation is found on the walls of either of the metering boxes or on the test specimen when the apparatus is opened at the end of a run, the results are invalidated and the operating conditions must be changed.



F.G. 7. WEIGHT VS TIME CURVES
Perimeter Leakage Test

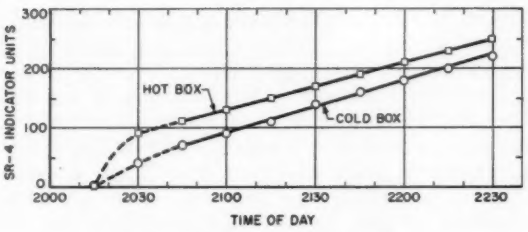


FIG. 8. WEIGHT VS TIME CURVES
Insulating Board Test

TABLE I
PERIMETER LEAKAGE CALCULATIONS

SPECIMEN
Material: 0.032-in. Type 3S aluminum sheet
Area: 8.16 sq ft = A

TEST CONDITIONS
Hot Metering Box: 85° F, 55.6% R.H.
= 0.6746 in. Hg vapor press.
Cold Metering Box: 60° F, 31.1% R.H.
= 0.1623 in. Hg vapor press.
Room: 72° F, 53% R.H., 30.15 in. Hg barom. press.

CALCULATIONS
Vapor Press. Gradient: $\Delta p = 0.6746 - 0.1623 = 0.5123$ in. Hg
Time of Stable Run (Fig. 7): 1 hr, 10 min
Welght Change (Fig. 7):
Hot Metering Box = 107.5 − 73 = 34.5 units
= (34.5) (2.845) = 98.2 grains
Cold Metering Box = 63 − 27 = 36 units
= (36) (2.657) = 95.5 grains

LEAKAGE RATES
From Hot Side: 98.2/(1.167) (0.5123) = 164 grains/hr in. Hg
Into Cold Side: 95.5/(1.167) (0.5123) = 160 grains/hr in. Hg
Average Leakage Rate: 162 grains/hr in. Hg

TABLE II
CALCULATIONS FOR INSULATING BOARD TEST

SPECIMEN
Material: ½-in. uncoated insulating board
Area: 8.16 sq ft = A

TEST CONDITIONS
Hot Metering Box: 85° F, 52.1% R.H.
= 0.6321 in. Hg vapor press.
Cold Metering Box: 60° F, 41.6% R.H.
= 0.2171 in. Hg vapor press.
Room: 75° F, 52% R.H., 30.08 in. Hg barom. press.

CALCULATIONS
Vapor Press. Gradient: $\Delta p = 0.6321 - 0.2171 = 0.4150$
Time of Stable Run (Fig. 8): 1 hr, 45 min
Weight Change (Fig. 8):
Hot Metering Box: 250 − 110 = 140 units
(140) (2.845) = 398 grains
Cold Metering Box: 225 − 70 = 155 units
(155) (2.657) = 412 grains

VAPOR FLOW
From Hot Side: 398/(1.73) (0.4150) = 548 grains/hr in. Hg
Less Perimeter Leakage = 162 grains/hr in. Hg
Net Vapor Flow = 386 grains/hr in. Hg
Into Cold Side: 412/(1.75) (0.4150) = 567 grains/hr in. Hg
Less Perimeter Leakage = 162 grains/hr in. Hg
Net Vapor Flow = 405 grains/hr in. Hg

PERMEANCE AND PERMEABILITY (see Eq. 1)
By Hot Metering Box Data: $M = 386/8.16$
= 47 grains/hr ft² in. Hg
By Cold Metering Box Data: $M = 405/8.16$
= 50 grains/hr ft² in. Hg
Average M (permeance) = 49 grains/hr sq ft in. Hg
Average μ (permeability) = Mx = (49) (0.5)
= 24.5 grains in./hr ft² in. Hg

TABLE III
SUMMARY AND COMPARISON OF RESULTS

MATERIAL	PERMEANCE (M)	PERMEABILITY (μ)	AVE. R.H. (%)	AVE. TEMP (°F)
½-in. Insulating Board (uncoated)	49	24.5	47	72.5
From Reference 1	50-90		40	
From Reference 2	44-92	12-41	25	
⅜-in. Plain Plasterboard	51	19.1	47	72.5
From Reference 1	50		35	
From Reference 2	29.1-34.4		57.5	
⅛-in. Masonite (pressed wood)	17.5	2.19	46	72.5
From Reference 2		1.4-2.4	37.5	

Test Calculations

The difference in strain-gage readings over a given number of hours during which steady flow conditions existed, when multiplied by the scale constant of the strain gage, gave the total weight of water vapor transmitted, in grains. This weight divided by the time of the run in hours, gave the grains of water vapor transmitted per hour, or (G/θ) in Eq. 1. From the hot and cold side temperatures and relative humidities, the vapor pressures were obtained from a table of properties of moist air; and the vapor-pressure difference, Δp, was determined. Dividing (G/θ) by Δp gave the grains of water vapor transmitted per hour per inch of Hg. This value had to be corrected for the perimeter leakage loss as determined by a separate test using an impermeable panel of 0.032-in. aluminum as the test specimen. (See Table I.) The area of the test specimen and its thickness being known, Eq. 1 was readily solved for permeance, M, or permeability, μ. (See Table II.) The results from the hot and cold side calculations should check closely, and the average value should be used.

Conclusion

The values obtained for vapor transmission from the first few tests using this facility seem quite reasonable when compared with results obtained by other investigators, as indicated in Table III. An

(Continued on page 27)

Correlation and Extrapolation Methods of Creep Data

MARIO PIO GOMEZ
*Associate Research Engineer, Boeing Airplane Company**

M. P. Gomez

Introduction

The time and expenditure necessary to carry out creep tests reproducing exactly the service temperature and load have lately made it almost mandatory to find ways of predicting long-time behavior from short-time tests. The observed fact that higher temperatures promote faster rates has influenced most of the attempts yet made.† Tests are conducted at high temperatures and short times, and a functional relationship is established between stress and a time- and temperature-dependent parameter. Though a mathematical expression of that functional relationship is seldom attained,[1,2,3] it is possible to show graphically its existence.

We shall discuss in some detail those methods which are of present technical importance and shall outline briefly others which have been proposed but which have not acquired wide acceptance. The methods will be presented in the chronological order of their publication.

NOMENCLATURE

ε = creep strain;
$\dot{\varepsilon} = r$ = creep strain rate
σ = stress;
σ_i = initial stress in a constant load test
t = time
T = temperature
l = length
f, γ, g = functions
$A, a, B, b, C, c, D, E, F, K, m, t_a, \beta, \zeta, \kappa, \mu, \nu, \sigma_a, \psi$ = constants

Andrade's Equation

The method generally accepted as the first to be attempted involves the finding of a mathematical formula relating strain and time:

$$\varepsilon = f(t)_{\sigma_i T}, \quad \text{or} \quad \varepsilon = f(t)_{\sigma T}. \tag{1}$$

Andrade[4,5] was the first one to propose an equation of this type (1910), though in his original expression he used l instead of ε.

His method, if successful, would allow the determination of the entire creep curve (or at least the first and second stages) from few observations at short times. Many creep curves can be represented by Andrade's formula:

$$\varepsilon = \varepsilon_0 - at^{1/3} - bt^1. \tag{2}$$

The observations needed are only those necessary to establish the constants in the equation. The tests can be run at service load and temperature. This method, however, generally fails because it is based on the assumption that creep curves can be expressed by simple mathematical formulas whose constants are not affected by the amount of deformation, whereas many new engineering alloys and even some pure metals, e.g., lead, exhibit curves which are not simple at all.

Machlin and Nowick Method

In 1947 Machlin and Nowick presented a paper[6] discussing stress-rupture as a rate process. Their results can be expressed by the equation,

$$\log t_r = \frac{A + BT - D\sigma}{T}, \tag{3}$$

where

$$\log D = E + FT,$$

which amounts to saying that if stress is plotted versus the logarithm of the time to rupture, a straight line would be attained. Previous investigators[7,8] had put forward the idea that the straight line relationship was obtained by a log-log plot.

If Machlin and Nowick were correct, it would then be possible to predict long-time behavior at any given temperature by running some tests at high stresses and plotting the rupture times versus the stresses on semilog paper. By linear extrapolation down to lower stresses, the corresponding rupture times could be determined; or, if time were a design requirement, the design stresses could be so estimated.

*Mr. Gomez received his degree of M.S. in Metallurgical Engineering at the University in 1958.
†Especially after 1952.

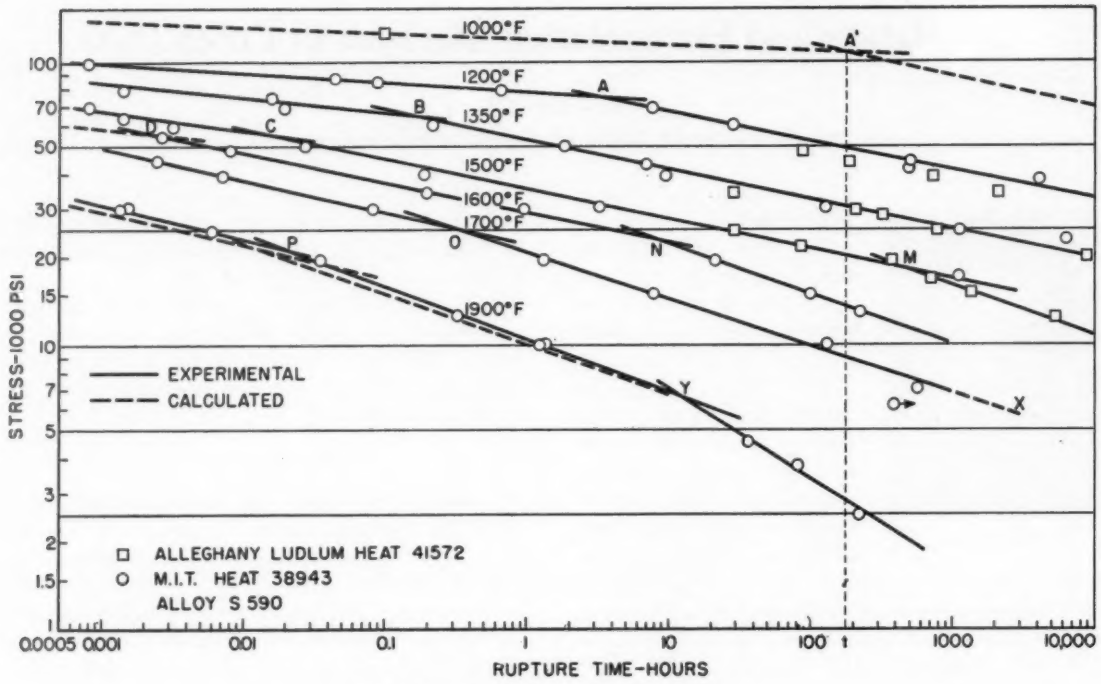


FIG. 1. LOG STRESS VS TIME RUPTURE PLOT
Reproduced (by permission) from *Transactions of the ASM*, Vol. 42, p. 725.

Grant and Bucklin Method

Grant and Bucklin in 1949 examined the rupture and minimum creep-rate data of several alloys. In their work[9] they used log-log and semilog plots. It then became quite evident that neither of their methods yielded straight lines through all the data for any single temperature. Log-log plots showed that data for each temperature fell on a series of straight lines, as shown in Fig. 1. Semilog plots produced a straight line at high stresses and a continuous concave upward curve at lower stresses, with a sharp breaking point in between.

Grant and Bucklin were able to relate the transition points between straight segments in the log-log plot to material instabilities. For instance, points ABC correspond to the transition from ductile transcrystalline failure toward the left (high stresses) to intercrystalline failure, characteristic of high temperatures, toward the right, of ABC. MNOP were related to over-aging. Furthermore, Grant and Bucklin plotted the log of the time to rupture corresponding to ABC and MNOP versus their respective temperatures. For points ABC they obtained a straight line and for MNOP a very smooth curve. They also plotted the slopes of the straight segments against the corresponding temperatures, with the result that points representing slopes of segments between equivalent points in Fig. 1 defined straight lines. A plot was also made of the log of the stresses corresponding to the intersection of all segments with the vertical line at 10,000 hours. The points corresponding to equivalent segments were found to lie on smooth curves. This last plot is not essential but it provides for further checking.

With all those data, Grant and Bucklin developed a new extrapolation method. They concluded that, since materials exhibit time-temperature material stability and instability relationships, it was therefore possible to extrapolate stability and instability data (such as slopes of segments and points ABC and MNOP) from high-temperature short-time tests to low-temperature long-time conditions. They actually showed an example of such an extrapolation which is in very good agreement with the experimentally obtained curve. As an example, they extrapolated the ABC curve in the log of the time to failure versus temperature plot, previously described, to a certain lower temperature, and they obtained point A′ defining a time to failure $t_{A'}$. Through an experimentally obtained point at the same lower temperature and high stress, they drew a line with a slope determined by extrapolation of data in the plot

of slope versus temperature. The first transition point, A′, was established at the intersection of that line with the vertical at the abscissa $t_{A'}$. From A′ they then drew a line (to the right) of a slope obtained also by extrapolation in the slope versus temperature plot. Figure 1 shows the calculated curves for 1000° F and the calculated and the experimental curve for 1900° F.

In the light of the experimental data they gathered, Grant and Bucklin analyzed the Machlin and Nowick method, finally concluding that the constants A and B are not temperature-independent as the latter held.

Grant and Bucklin used their approach in the study of minimum creep-rate data with results very similar to those of creep-rupture data.

Larson-Miller Method

Larson and Miller, in 1952, developed a method for correlation of data and prediction of life[10] based on an earlier work by Hollomon and Jaffee,[11] successfully correlating tempering data by establishing a graphical functional relationship between hardness, H, and a parameter depending on time and temperature:

$$H=f\,[T(A+\log t)]\,. \qquad (4)$$

This relationship can be shown to derive from the application of the Arrhenius equation to the processes involved in tempering.

Larson and Miller applied that parameter to the correlation of creep data obtained at different stresses and temperatures and for different lengths of time. In essence, what they did was to assume, as others[6,12,13,14,15,16] had done before, that creep rate can be expressed by an Arrhenius-type of equation,

$$\frac{d\varepsilon}{dt}=Ae^{-(Q/RT)}\,. \qquad (5)$$

They also assumed that the average strain rate was proportional to $1/t_r$ (t_r being the time to fracture) and that the activation energy, Q, was constant for a wide range of temperatures.

The Larson-Miller relationship may be formulated as follows:

$$LM=T(c+\log t_r)=f\,(\sigma)=Q/R\,. \qquad (6)$$

It is evident that the foregoing equation implies the stress dependency of the activation energy.

Figure 2 shows the way data are plotted by the use of the LM parameter. The vertical axis at the left indicates the stress levels (as log σ), and the axis of the abscissas gives the LM parameter. These two axes constitute the basis for the Larson-Miller plot.

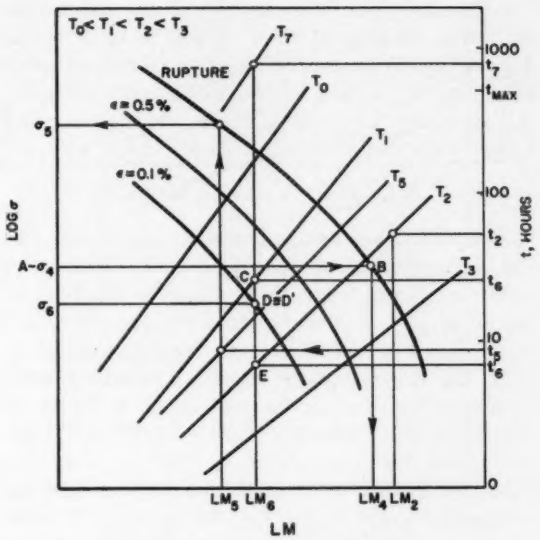


FIG. 2. EXAMPLE OF LARSON-MILLER MASTER CURVES

In addition, for practical purposes, a third axis is provided at the right, indicating log t_r. This axis, plus the lines T_0, T_1, T_2, T_3, helps to determine the LM corresponding to any pair of T and t_r (LM_2 for T_2 and t_{r2} in Fig. 2). When the Larson-Miller plot is used for correlation of data, the extreme temperatures shown in the plot (T_0 and T_3 in Fig. 2) are the minimum and maximum temperatures used in obtaining the experimental data. If prediction of life is sought for certain values, σ_4 and T_4, a horizontal line (AB) is drawn at σ_4, and its intersection B with the rupture curve $\sigma=f(LM)$ gives the corresponding LM_4. Then, from Eq. 6 and knowing T_4, it is possible to calculate log t_{r4} and t_{r4}. If we know T_5 and t_{r5}, σ_5 can be determined by following the inverse procedure.

The Larson-Miller method may be used for data not only of rupture but of a certain amount of deformation ($\varepsilon=0.5$ per cent or $\varepsilon=0.1$ per cent in Fig. 2), or for minimum creep rate, too. In order to illustrate how the Larson-Miller plot is made, let us assume that we are interested in data on 0.1 per cent deformation. The test will be run at temperatures high enough to produce the desired deformation in a reasonably short time. The stresses at which the tests are performed are selected on the basis of service needs. The time necessary to reach $\varepsilon=0.1$ per cent is then combined with the temperature at which the test was carried out, according to the Larson-Miller relationship. The LM so obtained and the stress at which the specimen was subjected, are then recorded as in Fig. 2. If the material obeys

the Larson-Miller relationship, all the points will fall on a curve and, for a certain level of stress, e.g., σ_6, points corresponding to two different temperatures (i.e., T_1 and T_2) will be coincident: $D \equiv D'$. The resulting LM_6 will, of course, be the same and equal to the respective combination of t and T:

$$T_2\,(c+\log t'_6) = T_1\,(c+\log t_6) = LM_6\,.$$

For other types and amounts of deformation, and for rupture data the procedure is the same. For minimum creep rate the parameter changes to $T(c-\log r_m)$, and the curve looks like a mirror image, with respect to a vertical axis, of the rupture curve.

In the original paper, Larson and Miller were convinced that c could be made equal to 20 for all materials and testing conditions. Though they recognized that c was not a universal constant, they maintained that the error introduced by such an assumption was negligible. It is now common practice to use a different value of c for each material. The value, which may vary from 10 to 40, is selected so as to produce the best correlation of data.

It is very important to realize the limitations of the Larson-Miller method, which is now being used throughout the United States. The limitations are mainly due to assumptions made by the authors which are not of the general validity they at first expected. For instance, the assumption that $1/t$ is a measure of the average strain rate does not apply to materials exhibiting brittle behavior. The assumption that Q is independent of temperature may lead to large errors.[17] This is especially true when the Larson-Miller method is used for the prediction of long-time (low-temperature) behavior from short-time (high-temperature) data. Even in the discussion of the original paper, Grant shows how prediction may differ from experimental results; a predicted life of 13,000 hours was experimentally shown to be only 840 hours. The use of the constant c for one material under all experimental conditions is also objectionable; Newhouse and Van Ullen[18] and Manson[19] have shown its stress dependency.

It is then advisable not to use this method for predictions of behavior beyond the limits of actual test data (i.e., beyond the longest testing time attained). This criterion must be borne in mind when using the Larson-Miller method so as to avoid misinterpretations; i.e., one can be misled by the fact that some interpolations in the plot are actually extrapolations with respect to the data used in preparing the master curve. In the example given previously, LM_6 may be assumed also equal to

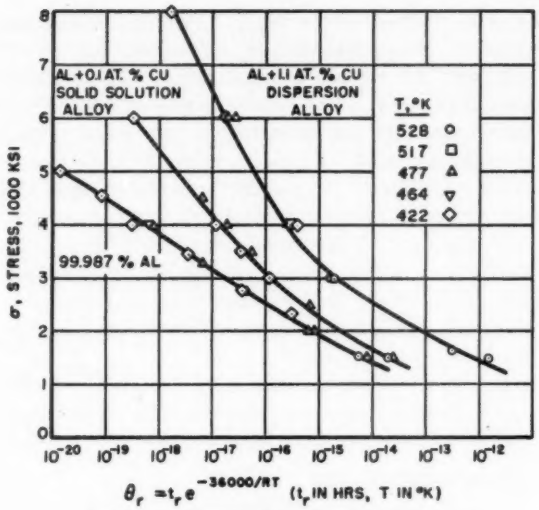


FIG. 3. EXAMPLE OF DORN'S METHOD
Adapted from *Transactions of the ASM*, Vol. 46, p. 117, courtesy of the ASM

$T_7(c+\log t_7)$ whereas, as shown in Fig. 2, T_7 is a temperature lower than any testing temperature and t_7 is longer than any testing time.

Despite the above-mentioned limitations, the Larson-Miller method has been found very useful and timesaving for correlation and comparison of data. It is also easier to handle than some other proposed methods.

Dorn's Method

Dorn and his associates have made many contributions to the field of creep during the past years. In 1952 Dorn and Sherby[20] proposed a method for the correlation of creep data of alpha solid solutions of aluminum. They determined that, for the alloys they tested, the total creep strain could be expressed as

$$\varepsilon = f(\theta, \sigma_1), \quad \text{or} \quad \varepsilon = f(\theta, \sigma)\,, \tag{7}$$

where

$$\theta = \int_0^t e^{-(\Delta H/RT)}dt\,, \tag{8}$$

ΔH being the activation energy for creep. It is easily seen that the authors, as others before them, have treated creep as a rate process. In cases where the temperature is held constant, Eq. 8 transforms into

$$\theta = te^{-(\Delta H/RT)}\,. \tag{9}$$

If the method is correct, the same creep strain will be obtained for the same value of θ, provided the stress, or the load, is held constant. (The stress and the load constant cases differ only in the form of the

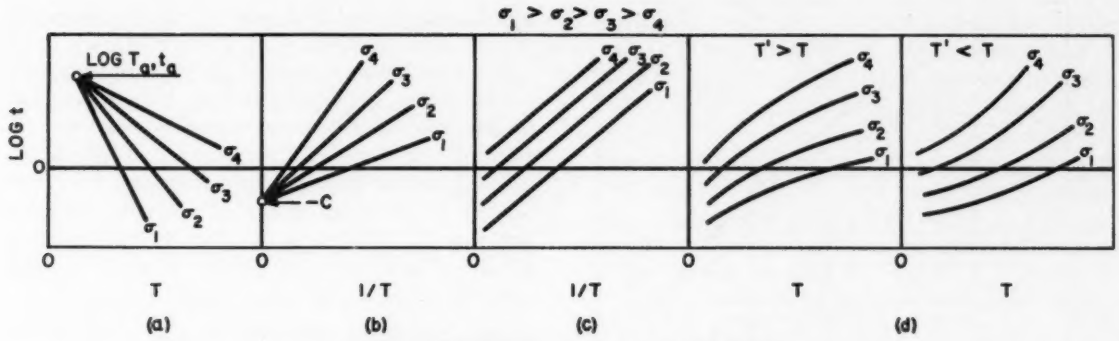


FIG. 4. COMPARISON OF CONSTANT STRESS LINES
(a) Manson's Method (b) Larson-Miller (c) Dorn's Method (d) Graham-Walles

function f.) Therefore, for a given θ_1,

$$\theta_1 = t_1 e^{-(\Delta H/RT_1)} = t_2 e^{-(\Delta H/RT_2)} . \quad (10)$$

If it were necessary to predict the time to reach a specified deformation at a lower temperature and the same stress, the time t_3 could be calculated by

$$\theta_1 = t_3 e^{-(\Delta H/RT_3)} . \quad (11)$$

Orr, Sherby and Dorn extended the method[21] in 1953 to the treatment of stress-rupture data. The parameter was found to be essentially the same,

$$\theta_r = t_r e^{-(\Delta H_r/RT)} ; \quad (12)$$

and when $\varepsilon_r \cong \text{const}$,

$$\theta_r = f(\sigma) . \quad (13)$$

The same type of experimental proof as outlined above holds in this case, and the parameters θ or θ_r could be plotted versus stress since, as follows from Eqs 7 and 13, θ and θ_r are single-valued functions of σ for $\varepsilon = \text{const}$. Such plots shown in Fig. 3 for θ_r versus stress should, if the method is good, yield smooth curves. Dorn and his associates have published many of these plots and the correlation obtained is acceptable.

By differentiation of Eq. 7, Dorn obtained the Z parameter first proposed by Zener and Hollomon:[22]

$$\dot{\varepsilon} = \frac{\partial \varepsilon}{\partial t} = \frac{\partial f(\theta, \sigma_1)}{\partial \theta} \frac{\partial \theta}{\partial t} = \gamma(\theta, \sigma_1) e^{-(\Delta H/RT)} . \quad (14)$$

For secondary creep rate Eq. 14 reduces to

$$\gamma(\theta_s, \sigma_1) = \dot{\varepsilon}_s e^{+(\Delta H/RT)} , \quad (15)$$

but since θ_s is only a function of stress,

$$\sigma_1 = g[\dot{\varepsilon} e^{+(\Delta H/RT)}] = g(Z) . \quad (16)$$

The parameter Z can be used to correlate creep-rate data in much the same way as θ and θ_r are used for deformation or rupture.

As an interesting consequence, Dorn found that the activation energies for the processes described above were equal to the activation energies for self-diffusion of the metals involved. He also found that his method is valid so long as the temperatures are higher than the minimum temperature of rapid recovery for the material considered, or about 0.4 M.P. Much of the disagreement found when applying his method is due to the use of temperatures lower than those prescribed.

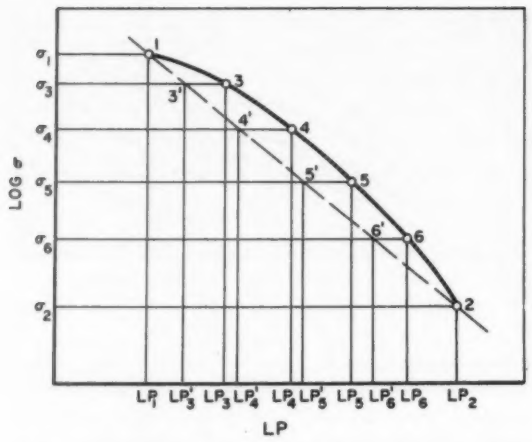
The method is limited in its technological application and its validity for prediction is questionable, but its formulation has special value in the study of the high-temperature flow of materials in general.

Manson and Haferd Method

Manson and Haferd developed in 1953 a method for correlation of data and prediction of behavior based solely on some experimental observations.[23] They found that, at least for some materials, if log t_r is plotted versus T, the points corresponding to tests carried out at the same stress fall on straight lines, as shown in Fig. 4a. Moreover, all constant stress lines converge to a common intersection point of the coordinates log t_a and T_a. Figures 4b, 4c, and 4d show, for comparison, the constant stress lines as implicitly assumed by Larson and Miller, Dorn, and Graham and Walles, respectively, in plots of log t_r versus $1/T$ or T.

In a later paper Manson and Brown[24] described a more general approach for the cases where the log t_r versus T plots do not produce straight lines. Since this approach has not been fully developed we shall not discuss it here.

In 1958 Manson[19] gave a detailed explanation of how to select the testing conditions (σ, T) so as to prepare master curves with a minimum expenditure of testing time. Once the assumption of constant stress lines convergency is accepted, it is evident that, by a proper selection of a pair of stresses,



F.G. 5. METHOD OF OBTAINING A MANSON MASTER CURVE

σ_1 and σ_2,* the constants log t_a and T_a can be found. With few tests at each of the two stress levels, enough points are obtained to draw the lines in a log t_r versus T plot. The intersection may be found either graphically or analytically by the least squares method. When log t_a and T_a are known, the two stresses σ_1 and σ_2 are plotted as functions of

$$LP = \frac{T - T_a}{\log t_r - \log t_a}, \qquad (17)$$

in a plot of log σ versus the "linear parameter" LP, as shown in Fig. 5. The two points so obtained define a straight line which can be used as a basis for the selection of other testing conditions. Other stress levels between σ_1 and σ_2 define points 3′, 4′, 5′, and 6′ on the straight line, and the linear parameters LP'_3, LP'_4, LP'_5, LP'_6. From each LP so obtained a temperature may be selected that allows for a reasonably short testing time. After the tests are performed, the actual times are combined with the testing temperatures, and the actual values of LP_3, LP_4, LP_5, and LP_6 are calculated, determining the points 3, 4, 5, and 6. The master curve is then drawn through points 1, 3, 4, 5, 6, 2.

Manson[19] showed a very successful application of his linear parameter. Lately, Betteridge[25] and Goldhoff[26] have carried on some comparisons between the different methods and both have concluded that the LP gives better correlation and predictions. However, it has not yet been extensively used or accepted. Its partial success led the Mond Nickel Company to design circular slide rules, based on the LP, that allow the calculation of t, T, or σ when any pair of them is known.

Much testing is yet required to establish the effectiveness of the LP parameter and, from a practical standpoint, the little extra accuracy that may be gained by its use would not warrant replotting the large amount of data already correlated by the LM parameter. From an analytical point of view, the fact that T_a falls in many cases in the range of service temperature (700° F for 17-22-AS) would apparently create problems of indeterminacy.

Graham and Walles Method

Graham in 1952[1] and in 1953[27] discussed the use of the phenomenological method in rheology, and particularly in creep. He then proposed a functional relationship between the four fundamental rheological variables σ, ε, $\dot{\varepsilon}$, and T, or their alternatives, σ, ε, t, and T. Graham developed in 1955, in collaboration with Walles,[2] a new method, based on his earlier work,[1,27] for correlating creep data which is entirely phenomenological in its nature and therefore does not pretend to represent any physical model of material behavior.

Graham and Walles started by assuming (but only as a working hypothesis) that material flow can be expressed by a power law similar to Nutting's[28] equation,

$$\psi\varepsilon = \sigma^\beta t^\kappa, \qquad (18)$$

which they wrote

$$\frac{\sigma}{\sigma_a} = \varepsilon^\mu \left(\frac{t_a}{t}\right)^{\xi T}. \qquad (19)$$

The relationships between constants and exponents of Eqs. 18 and 19 are evident. Since temperature has the virtue of affecting t more than the other variables, they decided to incorporate T in the exponent of t. Furthermore, they provisionally accepted the Larson-Miller parameter as a fundamental relation between time and temperature and rewrote Eq. 19 to read as follows:

$$\frac{\sigma}{\sigma_a} = \varepsilon^\mu t_a^{\xi(LM)}. \qquad (20)$$

It follows from Eq. 20 that if one were to plot log σ against LM a single straight line would be obtained. On the contrary, most of the data they analyzed showed master curves that could well be represented by a series of straight segments. Another discrepancy they observed was the fact that points corresponding to different testing conditions (constant stress rate $\dot{\sigma}_c$, constant strain rate $\dot{\varepsilon}_c$, and constant stress σ_c) fell consistently at different levels of stress for any given LM.

*The first two stresses, which should be as widely separated as possible, may be selected from a plot of tensile strength against temperature.

The next step that Graham and Walles took was to determine what modifications of their theory were necessary in order to account for the following facts:

1. Stress levels differ with loading conditions.
2. Data fall on straight segments with rather abrupt transitions between them instead of falling on a single straight line.
3. Accelerating and decelerating stages of creep should be taken into account in applying an equation such as Eq. 20.

In order to attain a better agreement between experimental results and their theory, they modified their original assumption that Nutting's equation relates finite changes among the variables and accepted the viewpoint that Nutting's formula establishes a relation among the increments of the same variables. They also introduced the Boltzmann memory principle so as to account for the history of loading, or mode of loading. Their results can be formulated as follows:

$$\frac{K\sigma}{\sigma_s} = \varepsilon^{\mu} t_s^{\zeta(LM)}, \qquad (21)$$

where K is a function of the beta function which depends on the mode of loading and gives the vertical displacement of the points due to the latter factor.

The influence of modes of deformation, the segmented appearance and abrupt transition of the master curves, and the representation of accelerating and decelerating stages of creep are taken care of by assuming that creep strain can be expressed by a series of terms like the second member of Eq. 21:

$$\varepsilon = \frac{(K_1\sigma)^{\beta_1}}{\sigma_{s_1}} t_{s_1}^{\zeta_1(LM)} + \frac{(K_2\sigma)^{\beta_2}}{\sigma_{s_2}} t_{s_2}^{\zeta_2(LM)} + \ldots \qquad (22)$$

After a reanalysis of the data was made, the authors concluded that although LM was good for correlation of data it was not sufficiently reliable for predictions. They also realized that because of the introduction of the memory principle the new method should account for strain-recovery upon unloading. They established that the strain contributed by terms in which $\kappa<1$ should be recoverable. (The constant κ is included in ζ.)

By analogy with Andrade's Eq. 2, Graham and Walles wrote the formula for strain when T and σ are constant as

$$\varepsilon = D_1 t^{\kappa_1} + D_2 t^{\kappa_2} + D_3 t^{\kappa_3} \qquad (23)$$

where

D_1, D_2, D_3 = constants, and

$\kappa_1 = 0,\ \kappa_2 = \frac{1}{3},\ \kappa_3 = 1$.

Furthermore, the terms in which $\kappa=0$ should produce a component of strain that is immediately recoverable; when $\kappa=\frac{1}{3}$, the strain is progressively recoverable; and for $\kappa \geq 1$, the deformation is permanent. Their conclusions accord with many of the experimental results concerning strain recovery.

Because of the difficulties they found with the use of LM as correlating parameter between time and temperature, Graham and Walles tried a different type of relationship between the fundamental variables. As had been suggested previously by Nutting[29] they placed temperature symmetrically with respect to the other variables;

$$\psi\varepsilon = \sigma^{\beta} t^{\kappa} T^{\nu}, \qquad (24)$$

but they realized that this type of equation would meet with the same objections as its forerunners, Eqs. 18 and 19, did with respect to stress. Therefore they introduced a "temperature memory principle" to account for the thermal history of the material. Owing to the lack of information on thermal histories of materials, they solved the integration problem by assuming that the materials are "born" at a temperature T', and so they changed Eq. 24 to read:

$$\psi\varepsilon = \sigma^{\beta} t^{\kappa} (T-T')^{\nu}. \qquad (25)$$

They also recombined time and temperature into a single parameter:

$$\phi^{\kappa} = t^{\kappa}(T-T')^{\nu}, \quad \text{or},$$

$$\phi^{\kappa} = [t(T-T')^{-A}]^{\kappa}, \quad \text{where } A = -\nu/\kappa,$$

so Eq. 25 may be written

$$\psi\varepsilon = \sigma^{\beta} \phi^{\kappa}, \qquad (26)$$

and the total creep strain is expressed as

$$\varepsilon = \sum_{p=1}^{n} C_p \sigma^{\beta_p} \phi^{\kappa_p}, \qquad (27)$$

where each term involves five constants, C, β, κ, A, and T', some of which may be the same for all, or at least for some, of the terms. Finally, by comparison again with Andrade's Eqs. 2 and 23, they equated creep strain as follows:

$$\varepsilon = C_1 \sigma^{\beta_1} \phi^{1/3} + C_2 \sigma^{\beta_2} \phi + (C_3 \sigma^{\beta_3} + C_4 \sigma^{\beta_4}) \phi^3. \qquad (28)$$

Graham and Walles have just published a work[30] which includes the detailed study of 103 sets of creep data. The data include stress-rupture, minimum creep rate, and hot-fatigue information. By the use of different numbers of adjustable constants they were able to correlate all the data, and, what is more important, they discovered many very interesting regularities underlying the behavior of many different materials under different testing conditions.

(Continued on page 30)

PATTERN RECOGNITION IN AN ELECTRONIC READER

PHILIP M. PAHL
Graduate Student in Electrical Engineering

DAVID L. JOHNSON
Associate Professor of Electrical Engineering

P. M. Pahl

D. L. Johnson

It is no longer news to read of an electronic or electromechanical device which has been developed to duplicate a specific human function and to perform that function far more efficiently and accurately than human capabilities permit. Even where perception of environment is involved, such devices have shown marked superiority over humans in measuring quantities and distinguishing such qualities as color, light, pressure, and sound. One function of extreme interest and significance is the ability to recognize general shapes and forms. The electronic reader is a device to distinguish among a variety of forms: a machine able to identify and describe the various language units it perceives. These language units are simply a collection of different forms—the many squiggles that are the letters, words, and other symbols comprising all written language. The electronic reader and its associated problems are the basis of this discussion.

In order to make a comprehensive study of this problem, the nature of the reader input and output must first be examined, i.e., the written language itself and the description which the device should make of what it has perceived. It is also of value to review what is known of the original reader, the human system. Many clues to the internal operation of any reading device may be found in analysis of the system operation of the eye, nerve, and brain.

Application of an Electronic Reader

Where might automatic high-speed reading devices be profitably used? Operations requiring the transformation of large amounts of printed matter to some coded equivalent, or involving the repeated examination of printed material to determine some particular bits of information, could use such a reader to advantage. An efficient automatic reader would make it possible to automatically sort and route a great deal of our mail, resulting in faster service and lower costs. Automatic reading devices would be doubly effective in the handling of many business problems, especially those connected with keeping records and processing numerical information where the transformation of routine alphabetical and numerical material to some machine code is involved. The reader would reduce the costs of these operations by speed and efficiency increases; it would also free operating personnel from the boring routine aspects of the job to concentrate on difficulties the reader might not be able to solve. In the fields of library research, weather data examination, and the development of reading aids for the blind, automatic reading devices would be extremely important.

A research project which has been of considerable interest at the University of Washington is the study of mechanical translation of languages from Russian to English. Before the mechanical translation of languages can compete with human translation, either on an economic or time basis, some means must be devised for the automatic introduction of the text language into the translation system. The development of an electronic reader is vitally important to the success of the over-all translation system.

The Reader Input

In order to appreciate the problems any automatic reading device must solve, some of the details of written language must be examined. The various language units which may be used for analysis and description of a written language include letters, syllables, words, clauses, phrases, sentences, and paragraphs. In most written languages, the number of letters is relatively small. English and other languages using the Roman alphabet generally use 26 letters, Russian has 32, German, 31, and Arabic, 28. In each alphabet some letters are quite similar in form, while others are totally different. Letters of different alphabets may be identical in form, while the sounds they represent are quite dissimilar. It is also known that certain letters are used more frequently than others. Samuel Morse took advantage of letter probability when developing his original telegraphic code. The relatively small number of letters in many alphabets indicates that letters may

be advantageously used as basic identification units by an electronic reader. When letters are combined with each other, the recognition becomes more complex. Considering the English alphabet, the possible number of two-letter combinations is 26^2, or 676; the possible three-letter combinations is 26^3, or 17,576. Fortunately, not all of these combinations are allowable, and others are used only infrequently. All languages seem to possess a preference for certain combinations which are predominately used. An analysis of English shows that about 70 syllables make up one-half of ordinary speech, but that 1,370 syllables are required to characterize 90 per cent of the language. If 93 per cent is assumed to represent essentially all of the English language, then the number of syllables is approximately 50 times the number of letters. The relationship between syllables may further reduce the recognition problem. Studies of telephone speech have indicated a preference for the consonant-vowel-consonent type of syllable, which occurred in one-third of the syllables spoken in the study. This type and the consonant-vowel and the vowel-consonant types made up three quarters of all the syllables examined. Assuming, then, that syllables could be determined and identified in written material, the use of certain syllables or letter groups would provide quick recognition of a large part of any written language.

Another language unit, the word, is more easily recognizable in print than are syllables. For almost the past 400 years it has been common practice to leave rather uniform spaces between printed and written words. The highly developed languages all contain large numbers of words, many of which are seldom used. Whereas the Oxford English Dictionary contains about 500,000 word entries, it has been estimated that good written fiction could be composed using only about 10,000 of these word types.

The problem of word recognition, rendered very complex by the number of words involved, does have simplifying aspects. First, there are certain preferred sequences of letters or syllables which make up the various words. Thus "nidificate" can be seen to be a very likely candidate for an English word, while "gelifkwaardig" has only a minute chance of belonging to the group. As is true with syllables, it has been observed that certain words of any language are used with more frequency than others. These words have a tendency to be quite short and are frequently monosyllables. Because of these simplifications, it may be useful to consider the use of words as basic identification units for an electronic reader, even though the number of words involved may be 1,000 times the number of letters.

The remaining language units, such as clauses, phrases, and sentences may all involve combinations of two or more words. Because of the large number of words to choose from, the totality of possible combinations is staggering. Combinations of words of any form would probably be completely impractical for automatic reader identification units.

In addition to the operating restrictions imposed by the choice of some specific language identification unit, a number of other considerations would cause difficulty for any automatic reader. All languages are written with a variety of punctuation marks which are normally quite significant to the exact meaning of the author's ideas. Thus it is certain that provision must be made for the recognition of punctuation marks. Various peculiarities of the printing process contribute to producing a non-uniform input. Examples are: the imperfect letter or the letter set just above or below the others on the same line, type faces of various sizes and styles, the practice of hyphenating words, the practice of squeezing or expanding the type to avoid hyphenating at the end of a line, and even misspelled words. Other imperfections such as smears and small spots in the paper might also cause confusion. Obviously the large variations in individual handwriting styles would be a formidable obstacle to overcome.

The Reader Output

In the previous section where possible applications of an automatic reader were considered, it was implied that the device would be of value as one of the parts in a larger system. That is, the reading device would sense the printed text, organize its responses into a unique description, then deliver this description to the next component in the system which would use what the reader had perceived. The principal requirement for the reader output is compatibility with the following component in the system.

It is necessary that the receiving component be supplied with information in a form which it can readily interpret and efficiently process. To meet this requirement, the reading device may have to express its output in a language unit different from the one the device itself uses for identification. This involves a transformation of what has been perceived to some different form; i.e., a translation process within itself. The reading device may recognize only the individual letters of the text, yet be required to produce an output in word form to yield optimum operation of the receiving component. In addition to the form of the reader output, the rate of output of the device must be compatible with the information-using component. The ultimate design of successful electronic reading devices may well depend upon knowledge of human visual processes. Human ability to see, classify, remember, and identify a great variety of shapes and forms is responsible for the widespread use of written materials as a form of communication. For this reason, certain of the aspects

of human sight, in particular those related to the recognition of form, must be considered. Research in the field of human recognition has by no means been completed, but many conclusions have been reached which may be of value.

The phenomenon of recognizing standard patterns may be illustrated by the following example. A literate person is able to recognize a given letter of the alphabet under a great variety of conditions. The letter may be large or small, close to the person or relatively distant, situated against a number of different backgrounds, normally oriented or upside down, written by hand or formed by one of several styles of type, and may even be in a plane almost parallel to the reader's line of sight. Despite these diversities, recognition of the given letter is still possible. Recognition is achieved so long as the letter retains enough of its invariant qualities to make it distinguishable from the remainder of the alphabet. Furthermore, establishment of the letter's identity assumes a decision that the letter was not one of the others in its group.

One reason for human success in pattern recognition is that our varied visual inputs become highly standardized after being received. This is accomplished by the complex action of various eye-muscle feedbacks and other mechanisms which are less well understood. There are several ways in which the human system attempts to simplify recognition by standardization of visual inputs. First, objects which attract our attention are viewed so that their images fall on the fovea, the central portion of the retina where perception of form is enhanced. The images are also focused on the retina to make them as sharp as possible. Next, when the object is one which is most familiar to us in a particular orientation, a certain mechanism tends to produce this orientation, regardless of the object's actual position. Finally, a process of accommodation causes the eye to receive its most intense impressions at the boundaries, i.e., discontinuities of color or illumination. The result is that our visual images are reduced more or less to outlines. This last process may be compared with the "stopped-spot" principle of television scanning. In this system, the scanning spot passes rapidly over areas of no contrast but halts temporarily at boundaries, the positions of which are coded for transmission. The advantage of the system is that signal redundancy is greatly reduced.

The standardization of visual information may be thought of as one step of a data reduction process. It has been estimated that the information capacity of the human eye is roughly 4×10^6 bits per second; but that the perceptual intake rate of the mind is on the order of a few hundred bits per second. The mind can therefore use only a minute fraction of the information available at the eyes. It can be concluded that we retain only the most significant portions of our visual images for perceptual purposes and discard the remaining quantity of relatively useless information. After the input standardization, the structure and operation of the optic nerves and visual cortex apparently accomplish the remainder of the data reduction.

How do these visual inputs, reduced by the human system to standardized images, relate to the problem of pattern recognition? While not conclusively proved, it is fairly certain that recognition is a comparative process taking place in the mind. The comparison is between some image presently seen and the multitude of previously seen images stored in memory. Storage of images occurs as one of the three established human memory processes. One of these processes may be termed a picture memory which in many ways may resemble a series of snapshots of our environment, including our familiar patterns. Each snapshot may be made up of several hundred spots. The number of spots has not been conclusively measured and probably varies from picture to picture. Each spot has a binary bit or yes-no characteristic. It is estimated that the pictures may be stored at a maximum rate of about 10 per second and a person may well store as many as 10^{10} of these pictures in his lifetime. The stored snapshots are available for recall in the comparative process of recognition. Just how this comparison is made is not definitely known. Evidence obtained thus far indicates that the comparison is some sort of statistical process which involves picking the most likely picture, considered as a population of binary bits, with which to associate our perceived data. The minimum time required for recognition to take place is approximately 0.1 second.

Reading is a highly complex type of pattern recognition worth special consideration. In reading, it is known that the eyes are stationary about 90 per cent of the time, moving only with rapid jerks or saccades. Various experiments suggest that perception occurs almost entirely during the stationary periods. The eyes see a sharp image only at the fixation points. Sufficient clues as to general contours of other letters or words in the immediate vicinity of the fixation point are simultaneously received to enable recognition of several letters, a word, or more than one word. Recognition, then, takes place not only at the fixation point, but over a relatively large area. A significant point is that the eye receives information about what lies ahead of the fixation point as well as what follows it. This result, coupled with the reader's intuitive knowledge of statistical and syntactical properties of the language, seems to provide a feedback which determines where the next fixation point will occur. The distance

covered by the saccades, and hence reading speed, is highly flexible, depending on the rate of perception of the text information.

Finally, there are recognition problems which the human cannot resolve on the basis of one particular object. The object must be viewed or associated with other related patterns before absolute identification is possible. If one were asked to identify the symbol "p" by itself, one could not determine whether it was a "p" or a "d" until its orientation with respect to other letters was known.

Reading Devices Already Developed

During the past forty-five years, numerous attempts have been made to construct devices which would effectively recognize printed material. The objectives of such devices may be classified generally into three categories: to furnish the blind with reading aids, to expedite the feeding of alphanumeric data to business machines, and to study theories concerning human visual processes. Study of these devices shows several common characteristics. The following statements apply generally to all of the previously developed reading devices, especially those of recent design:

1. All use individual characters, letters or numerals as identification units.
2. Characters are vertically scanned by a single light source or some "flying spot" equivalent.
3. There are numerous passes of the light source over each character, resulting in a minute point-by-point examination of each character.
4. Recognition is restricted to a small group of characters which each device has a predetermined ability to recognize.
5. Compared with the human visual system, the devices are only moderately effective in recognition of a variety of type size, style, and quality.
6. Few have any provision for automatically shifting from one line of print to the next.

Recognition Logic

Consideration of the operating characteristics just enumerated provided the direction for the experimental portion of this project. It was believed that reading devices of the type just described might realize much better performance, particularly increased speed, if either or both of the following techniques were used: horizontal scanning of an entire line of print, especially if scanning could be accomplished at a speed comparable to a single vertical scan of a single character; and parallel handling of the scan information, assuming that more than one scanning source be effectively generated and used. It was decided to investigate the possibility of developing and mechanizing a recognition logic based on multiple horizontal scanning and parallel handling of the resultant information. Speed of operation was not an objective of the device to be constructed. It was also decided to examine the effectiveness of a coarse scan of each language unit to see whether accurate recognition was possible when a minimum of horizontal scans was used.

The first step in the development of a recognition logic was the choice of a language unit to be used for identification purposes; i.e., selection among such possibilities as letters, syllables, words, etc. In the first stages of investigation it was hoped that a relatively straightforward means might be devised to use words as reader-identification units. The problems in mechanization of such a device, however, were so involved as to require extremely extensive and expensive equipment. To permit a comparison between the efficiency of vertical and horizontal scans, the use of individual alphabetic letters as the basic identification unit was adopted—specifically the use of small printed Russian letters.

Following the choice of the 32 Russian characters as basic identification units, it was necessary to determine the properties of each letter which distinguished it from the others and permitted unique identification. These properties might be termed the invariant characteristics of each letter. The method used to determine the characteristics to establish a given category was placing the letters upon a fine grid. To approximate the information that might be available to a narrow horizontal scanning spot, a slotted card was placed over the letters, leaving only a horizontal display of one section of the print. Five equally spaced horizontal scans were assumed for the study. The top scan intersected the print of only two letters; the bottom intersected only six letters. Based on this observation, the first two categories of letter characteristics were chosen. Any letter which extended above its fellows was assigned to Category 1; those which extended below were assigned to Category 2.

The next result of the analysis was the observation that a scanning spot would intersect the print of each letter a certain number of times and that the number of intersections depended on the vertical position of the particular scan with respect to each letter. The number of scan intersections per letter is usually one, two, or three. These scan intersects with the print may be converted to electrical pulses which can be counted and used as identifying characteristics. On this basis, eight additional categories were established which are entirely dependent upon the intersection-counting process, i.e., the number of scan intersections along the top, center, and bottom of a given letter. It should be noted that the length

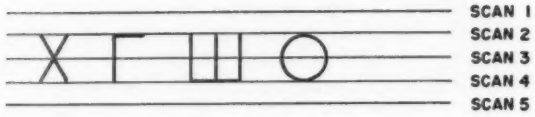


FIGURE 1

of the intersection will not affect the counting. A scan through the center of an "H" and an "X" would each produce one pulse, and although the pulses are of different length, they are both counted as one. The scan intersect count is not required for the top and bottom scans since they always have a one count when referred to the Russian alphabet.

Subsequent letter analysis revealed the usefulness of what might be considered as letter extremities. For the purposes of this work, an extremity was considered to exist whenever one or two portions of a letter extended appreciably to the right or left of the main body of the letter. Further, existence of an extremity was based on the upper and/or lower portion of the letter extending beyond the center portion. No extremity was assumed to exist when the reverse was true. The extremity indication would consider only the three central letter scans. Because multiple horizontal scans must be used some of which would intersect at different times from others, it was decided to use this time difference in the reading device to determine letter extremities. The letters shown in Fig. 1 serve to illustrate the extremity definition. Picture the three central scanning spots moving simultaneously in a vertical row along the paths indicated. Scans 2 and 4 will give both right and left extremities on the first letter. The next letter has only a left extremity on Scan 2, while the following two letters have no extremities existing. With the establishment of extremities as identifying characteristics, four more categories were added, making a total of 14, and the analysis was essentially complete. Table I lists the fourteen categories.

TABLE I

CATEGORY	CHARACTERISTIC	SCAN NUMBER	NO. LETTERS INCLUDED
1	upward extending	1	3
2	downward extending	5	6
3	one pulse	2	17
4	two or three pulses	2	14
5	one pulse	3	16
6	two pulses	3	10
7	three pulses	3	6
8	one pulse	4	20
9	two pulses	4	9
10	three pulses	4	2
11	one extremity left	2,3,4	4
12	two extremities left	2,3,4	4
13	one extremity right	2,3,4	3
14	two extremities right	2,3,4	5

Note that Category 4 includes both those letters with two and three intersection pulses on Scan 2. These letters can be uniquely determined without establishing a three-pulse category for Scan 2.

An examination of the categories when related to the individual letters shows that four letters all belong to the same categories and therefore cannot be uniquely determined. Several methods could be applied to solve this problem. One would be to sense the difference between large and small dark areas so that a short pulse would not be considered the same as a long one. Another would be an increase in the number of scans from a total of five to seven. For the purposes of this research, five scans were considered sufficient to demonstrate the developed recognition logic and no attempt was made to resolve the ambiguity of the four letters.

A Russian Character Reader

The next step following development of the recognition logic was the design and construction of an electronic device capable of using the logic to identify Russian letters. For design purposes, the proposed device was divided into three functional sections: scanning, pulse forming, and logical circuitry. It was considered that the logical circuitry section in which actual identification of each character would take place presented the greatest degree of difficulty. Accordingly, design of the reader was initiated in this area. Over-all simplicity was a design objective.

The recognition logic developed in the previous section requires accomplishment of three tasks for recognition to take place. In order to identify a given character the logical circuits must decide whether a portion of the letter has been seen by Scans 1 and/or 5, count the number of returns from Scans 2, 3, and 4, and also determine whether the letter has extremities and count and identify the extremity returns. To minimize information storage, the operations should occur nearly simultaneously so that each letter may be identified by the time the five scanning spots pass over it. This operation implies that additional logical circuitry would be required to sense when the scanning spots had completely passed each letter and to use this information to reset the totality of the circuitry. The use of relays in all logical circuitry was assumed, both because of ease of procurement and the correspondence of relay action with Boolean logic.

The counting function requires a capability to count to one, two, or three and produce a distinct output corresponding to the resultant count, then be reset to the zero-count condition regardless of where the counter has stopped. A separate counter is required for each of Scans 2, 3, and 4. Suitable relay counting circuitry was designed to accomplish the requirement.

The design of circuitry to determine extremities was accomplished by using a time-dependent form of Boolean algebra. It should be recalled that a letter with an extremity is defined as having at least the upper or lower portion extending well to the right or left compared with its center. Considering the left side of a letter, an extremity exists if returns from Scans 2 or 4 can be sensed by the reader before there is any return from Scan 3. The scanning spots are assumed to move from left to right. In concise terms, Category 11 is established by the condition, $2(t_1) \sim 3\ (t)$, or $4(t_1) \sim 3\ (t)$, where t_1 is the time when returns are sensed from Scans 2 or 4 and t is any time from the reset, t_0, up to but not including t_1. Categories 12, 13, and 14 may be established by the same form of Boolean notation. Relay operations in the extremity circuits are basically the same as in the counting circuitry with additional "hold" and "dropout" relays to provide the time of dependence.

During the development of the counting and extremity-determining circuitry, it was noted that certain letters might not be identified correctly unless provisions were made to obtain maximum information from their return pulses. Differentiation of the scan pulses permitted identification to be used for counting and identifying left- and right-side extremities.

With the circuitry discussed thus far, it is possible for a reading device to determine the categories to which a scanned letter belongs. In short, this is accomplished by energizing a combination of three more relays out of a possible 14. The energized relays, in turn, supply voltage to their respective category output leads. The next requirement is for circuitry which can sense and indicate which letter has been scanned, given that some combination of leads is at some non-zero potential. Each unique combination of active terminals may be identified with the scanned letter by at least two methods. One is by use of a logical "tree" structure. Another method might be by means of a logical diode matrix. Because of materiel difficulties, it was decided to eliminate this portion of the reader and make use of visual recognition attained by matching patterns of active lights. This method throws the burden of decoding the simplified logic essentially upon the human receiver.

The final requirement of the logical portion of the reader was the ability to determine when one letter had been completely scanned and then to reset the other logical circuitry to its original state. In this way, the reader, after scanning the first letter, would automatically reset to process information from subsequent ones. It was hoped originally that, when each of the five scanning spots no longer touched any portion of a letter, scanning could be considered finished and the reset action initiated, but there are several letters which frustrate such a plan. Consider the letter "X." When the scanning spots are in the position shown in Fig. 1, none of the scans are intersecting the marks of the letter. Yet it is clear that if reset were to occur at this instant, the letter would be incorrectly identified. The use of a single vertical scan used only for reset operation would seem to be the optimum solution of this problem. In the reading device itself, manual reset was used.

The construction of the pulse-forming circuits required extensive experimentation. A type-930 gas phototube was found adequate when used with triode amplifiers. The scanning mechanism consisted of two spotlights mounted behind a flat plate with five holes. The plate was mounted so that the five holes were in a vertical row. At one side of the plate were mounted the five phototubes; each of the holes in the plate was aligned with one of the semicyclindrical phototube cathodes. A short grooved track was mounted on the same chassis with the plate, and the phototubes and a piece of plate glass with source letters marked with a grease pencil was passed down the track. The interruption of the light to the phototube caused by the letter passing through the beam activated the logical circuitry and permitted identification of the letter. Practical readers must scan the printed page with minute beams of light which will be reflected from the page in different intensities for mark or no-mark. The photo-sensitive transducer receives the reflected light and this information is delivered to the logical circuitry for identification.

Discussion of Results

As previously stated, the group of characters to be identified was the Russian alphabet, specifically the 32 small printed letters. The characters tested were modeled after those shown in Mueller's *Russian-English Dictionary*. Of the 32 letters in the Russian alphabet, the reader placed 30 in the categories predicted. Categorization other than that predicted was caused by more sensitivity of the reader than had been expected. The device gave these final results:

Letters correctly identified . . . 30 of 32, or 94%
Letters uniquely determined . . . 26 of 32, or 81%

The results obtained indicate that a recognition logic based on horizontal scanning is highly effective in identifying lower-case printed Russian letters. The results could have been degraded or enhanced, however, by several factors worth considering. First is the shape of the letters themselves. A consistent and exact reproduction of the shapes from which the logic was derived would give essentially 100 per cent identification. For different types of letter formation (type forms) it might be necessary to adjust the relative scan positions.

(Continued on page 32)

Molecular Association in the Vapor Phase System Acetic Acid, Ethyl Alcohol, Ethyl Acetate, and Water*

LYNDON R. BABCOCK, JR.
Graduate Student in Chemical Engineering

L. N. JOHANSON
Associate Professor of Chemical Engineering

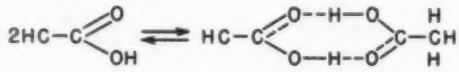
L. R. Babcock, Jr.

Vapor phase association has long been a subject of interest to chemists and others concerned with the properties of gaseous substances. For over seventy years deviations from gas laws have been attributed, in part, to reversible partial molecular association.

The term "molecular association" is usually applied to describe an abnormally large molecule made up of several distinct smaller molecules held together by weak linkages, such as the hydrogen bond.

The hydrogen bond is thought to be a result of the extremely high polarity of the hydrogen atom. This atom is, in a sense, a perfect dipole because it has only two parts, one positively charged proton and one negatively charged electron. Hydrogen bonding is strongest with highly electronegative elements, such as fluorine, oxygen, nitrogen, and chlorine, in that order.

The acetic acid dimer is an example of association thought to be caused by double hydrogen bonding:



(1)

The heat of dimerization for this reaction is 15.05 kcal/g. mol or 7.5 kcal/g. mol of single hydrogen bonds. This compares with 109 kcal/g. mol for a normal covalent oxygen-hydrogen bond.

A second type of molecular interaction is often of interest. Molecules which are not symmetrical exhibit what is known as a dipole moment. Water is such a polar molecule, having both a positive center and a negative center in the molecule. Methane, conversely, is electrically symmetrical and has no dipole moment. The positive end of one polar molecule can form a bond or interaction with the negative end of another molecule, although the strength of such a bond is very much less than the aforementioned hydrogen bond. Most molecular association of polar molecules is usually thought to be a combination of both dipole interactions and hydrogen bonding.

L. N. Johanson

Methods which have been used to study molecular vapor association include spectroscopy, to reveal the presence of the associating species,[2] ultrasonic velocity, which is dependent on the molecular weight and heat capacity of the gas,[3] heat capacity, and thermal conductivity.[4,5,6,7] Deviations from accepted formulas in the latter three methods are attributed to abnormal molecular weight.

The classical and most straightforward method used to study molecular association is the gas density method. Using this method one simply encloses a known weight of gas in a known volume at measured pressure and temperature and then calculates the molecular weight by means of the ideal gas law.

After calculating the molecular weight by any of the above methods, one can calculate the degree of association or dissociation. If association is assumed to involve only dimer and monomer molecules, the association equilibrium constant, K_p, may be defined thus:

$$K_p = \frac{(p_{\text{monomer}})^2}{p_{\text{dimer}}}. \qquad (2)$$

If α = mol fraction of dimer dissociated, and P_T = total pressure, the resulting expression for K_p is:[8]

$$K_p = \frac{4\alpha^2 P_T}{(1-\alpha^2)}. \qquad (3)$$

If the correct associating mechanism has been assumed, K_p will remain constant when the pressure is varied.

Review of Literature

Acetic acid has long been a favorite for molecular association studies because at low temperatures and high pressures acetic acid vapor exhibits a molecular weight approaching 120 instead of the formula weight of 60.

* Condensed and arranged from Mr. Babcock's thesis for the degree of M.S. in Chemical Engineering, 1958.

Probably the earliest thorough study was published by Ramsay and Young[9] in 1886. These two early scientists, referring to organic acids in general, drew the following conclusion from their painstaking work:

> . . . . At moderately low temperatures, these substances invariably show vapor densities which lead to the conclusion that the structure of their molecules is not so simple as that expressed by their formulae.

Down through the years other investigators who have studied acetic acid vapor density have usually postulated polymers higher than the dimer. Johnson and Nash,[10] using a method similar to that referred to here,[8] postulated the presence of trimers in addition to dimers.

Ritter and Simons,[11] however, postulated that the tetramer is more likely than the trimer, since a tetramer structure does not require breaking of dimer bonds for its formation, as does the trimer structure.

Later, however, Weltner[2] interpreted infrared spectra to mean that only monomer and dimer were present. He stated that trimer and tetramer postulations were possibly due to faulty data caused by the adsorption of acetic acid vapor on glass and mercury. It will apparently be some time before the structure of acetic acid vapor will be agreed upon.

Herman[12] postulating both dimers and trimers, was able to fit the original data of Ramsay and Young very well.

Work on other less spectacular polar gases has also been carried on, including studies of Sinke and DeVries,[6] Bennet and Vines,[4] and Foz, Colomina, and Garcia,[5] which suggests the presence of ethyl alcohol vapor polymers and water vapor dimers.

Much less work has been done on mixtures of polar vapors. It would seem possible and probable that hydrogen bonding could occur between two different kinds of molecules.

At Oxford, J. D. Lambert and associates[13] have been studying polar vapors alone and as mixtures with nonpolar substances, and have obtained moderate deviations from Bertholet's equation of state, attributed to association.

Considerable association would appear possible in mixtures of two very polar vapors where all three possibilities of interaction present themselves:

$$E+F \leftrightarrows EF$$
$$2E \rightleftarrows E_2$$
$$2F \rightleftarrows F_2$$

At the time this work was undertaken, the authors were unable to find results of any such study recorded in the literature.

This research dealt with mixtures of polar vapors in the system ethyl alcohol, water, acetic acid, and ethyl acetate. The first three components have been shown to associate with themselves. Comparable information is lacking concerning ethyl acetate.

The selection of this system stems initially from the study of A. J. Herrman[12] on the kinetics of the reaction between acetic acid and ethanol, catalyzed by an ion exchange resin catalyst.

Published values of the vapor phase equilibrium constant for ethyl acetate formation from acetic acid and ethanol were compiled by Herrman and supplemented by his own data at subatmospheric pressure. Considerable discrepancy existed, both between published values of the equilibrium constant at atmospheric pressure, and between such results and subatmospheric pressure results. It was postulated by Herrman that these discrepancies may be a result of vapor phase nonideality. Many possibilities of association exist in the system acetic acid, ethanol, ethyl acetate, and water, in addition to acetic acid association. The latter was taken into account by Herrman by means of dimer and trimer association constants, obtained by curve-fitting the data of Ramsey and Young.[9]

The objectives of the present investigation were to discover, quantitatively and qualitatively, any abnormal molecular weights due to vapor phase association of unlike molecules, by utilizing vapor density measurements. Specifically, ethyl alcohol, water, ethyl acetate, and acetic acid were studied at pressures from 0 to 1 atm and temperatures from 70 to 115° C.

Pressure-volume-temperature relationships were obtained first for the various binary mixtures, and then for an equimolar quaternary mixture. Apparent molecular weight, $M=(RTW)/P_TV$, was plotted versus pressure and compared with the ideal molecular weight versus pressure curves to ascertain the amount of association between unlike molecules. The use of the word "ideal" needs some explanation: Each component behaves as if it were alone at a total pressure equal to its partial pressure in the mixture; there is no interaction between unlike molecules. In other words, acetic acid associates independently of the other components, which serve only to dilute the acid.

Apparatus

A modified mercury displacement PVT apparatus (Fig. 1) was used to measure pressures and volumes. Constant temperature was achieved by placing the apparatus inside a 4-inch diameter insulated Pyrex pipe through which oil was pumped from a 10-gallon thermostated reservoir at a rate of 4 gallons per minute. Temperature was measured by means of two 0.1° C thermometers immersed in the oil. Liquid samples were measured in a specially made 1-ml burette. Temperatures, mercury column heights, and burette volume changes were measured with a cathetometer mounted approximately 4 feet from the columns.

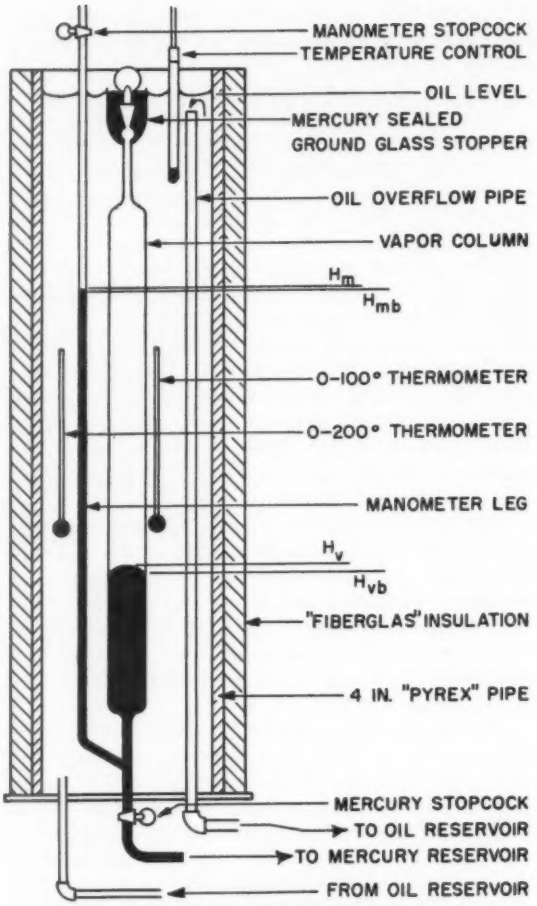


FIG. 1. MERCURY DISPLACEMENT APPARATUS
(Not to scale)

Temperature control was $\pm 0.3°$ C. Mercury-in-burette heights were read to ± 0.001 cm. Mercury-in-column heights were read to ± 0.01 cm. The latter readings were less accurate than the burette heights because of imperfections in the Pyrex pipe and turbulence in the oil bath.

The type of apparatus used had several advantages. Sample addition was rapid, and several different PVT measurements could be made on a single sample. Pressure and volume were easily changed by adding or removing mercury at the bottom of the columns by raising or lowering a mercury-filled bucket connected to the columns by a rubber hose.

There were also some disadvantages. Many corrections for mercury density and capillarity were necessary. It was almost impossible to keep the mercury dry. At times the mercury seemed to remove sample by adsorption and mechanical occlusion; later, bubbles would rise up through the mercury. This caused perhaps 0.5 per cent error. Liquid samples were very small, from 0.05 to 0.2 ml, and errors due to contamination and evaporation were very apparent with such small quantities. Several milliliters of air were admitted with each sample. Mercury vapor was present, but a correction was made, assuming mercury vapor to be a perfect gas. The correction varied from 0 at low temperatures to a maximum of 0.6 per cent at 115° C, below 10-cm Hg pressure.

TABLE I
SUMMARY OF COMPOSITIONS STUDIED

RUN	SYSTEM	WEIGHT FRACT. (w_i)	ZERO PRESSURE		SAMPLE WEIGHT (grams) (W)
			MOL FRACT. (Y_{i0})	MOL WT (M_0)	
I	Acid	1.000	1.000	60.05	0.1224
II	Water	1.000	1.000	18.02	0.0552
III	Acid	0.950	0.850	53.74	0.1212
	Water	0.050	0.150		
IV	Acid	0.769	0.500	39.04	0.1315
	Water	0.231	0.500		
V	Acid	0.406	0.500	74.07	0.1786
	Acetate	0.594	0.500		
VI	Acid	0.566	0.500	53.06	0.1165
	Alcohol	0.434	0.500		
VII	Acetate	0.891	0.627	61.9	0.1578
	Water	0.109	0.373		
VIII	Acetate	0.989	0.949	84.5	0.2045
	Water	0.011	0.051		
IX	Alcohol	0.719	0.500	32.04	0.0825
	Water	0.281	0.500		
X	Alcohol	0.217	0.25	53.06	0.1315
	Acid	0.283	0.25		
	Acetate	0.415	0.25		
	Water	0.085	0.25		

Reagent grade acetic acid, boiled distilled water, U.S.P. anhydrous ethyl alcohol, and reagent grade ethyl acetate were used for making up samples. It was found necessary to prepare a distilled "heart cut" of the ethyl acetate to reproduce the expected molecular weight, probably because of a slight water contamination of the previously opened bottle.

Details of the method of conducting the experiments, and basic observations made, are available in Reference 8.

A summary of compositions studied, including weight per cent of each component, mol fraction and molecular weight at zero pressure, and weight of sample appears in Table I. Typical run results, including pressure, volume, temperature, apparent molecular weight, ideal mixing molecular weight, and the deviation from the ideal mixing molecular weight are shown in Table II. A summary of average molecular weight deviations is given in Table III. Apparent molecular weight and ideal mixing molecular weight results are plotted versus pressure in Figs. 2, 3, 4, 5, and 6. Complete results may be found elsewhere.[8]

TABLE II
PRESSURE-VOLUME-TEMPERATURE DATA

Run	Temp (T) °C	Pressure (P_T) cm Hg	Volume (V) cm³	Molecular Weight		Deviation (d) %
				Apparent (M)	Ideal (M_T)	
I-1	342.8	10.95	235.1	101.5	102.3	−0.8
II-1	371.2	50.98	137.1	18.2	18.2	0.0
5		10.85	651.3	18.1	18.0	+0.6
IV-1	387.7	74.65	93.9	45.3	46.7	−3.0
7		15.41	500.8	41.9	42.8	−2.1
8	371.2	42.54	155.4	46.1	47.0	−1.9
13	342.8	15.95	367.2	48.0	48.2	−0.4
VI-1	387.7	75.33	59.1	63.2	63.7	−0.8
3		33.39	141.6	59.6	60.5	−1.5
4		26.49	181.0	58.8	59.8	−1.7*
8		9.92	510.9	55.6	57.0	−2.5
9		9.73	516.7	56.0	57.0	−1.8*
10	371.2	49.13	84.4	65.0	64.6	−0.6
13		9.53	487.2	57.9	59.0	−1.9
14	342.8	20.55	181.4	66.8	66.1	+1.1
16		6.42	636.0	60.8	61.8	−1.6
IX-1	371.2	77.02	79.0	31.4	32.3	−2.8
6		11.79	524.0	31.0	32.0	−3.1
X-1	371.2	72.43	75.3	57.1	57.9	−1.4
6		11.41	515.8	53.0	54.9	−3.5

*Reaction check point. See discussion.

TABLE III
AVERAGE DEVIATIONS OF EXPERIMENTAL FROM IDEAL VALUES

Run	III	IV	V	VI
Average Deviations				
at 115° C	−0.8	−3.1	−0.9	−1.7
at 98° C	−1.0	−2.2	−1.5	−1.3
at 70° C	+1.1	+0.4	+1.6	+0.4
Deviation, 70° C, Minus Deviation, 115° C	1.9	3.5	2.5	2.1

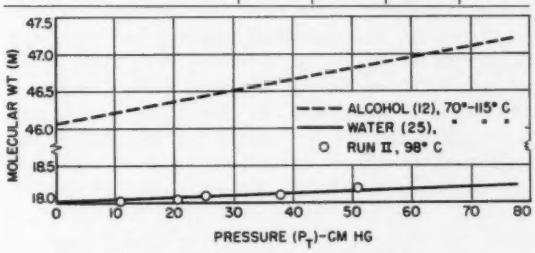


FIG. 2. VARIATIONS OF MOLECULAR WEIGHT WITH PRESSURE
Pure alcohol and pure water

Discussion of Results

Several distinct types of relationships were found; these will be discussed separately.

Pure Components. These were measured to assure that the apparatus was functioning properly. Run II (Fig. 2), pure water, gives an indication of the accuracy and precision which can be obtained with a pure sample. The maximum arithmetic deviation of the calculated molecular weight from the theoretical value was 1.3 per cent, the minimum, 0 per cent. Neither the accuracy nor the precision was quite as good with acetic acid as with water. The larger maximum deviation of 1.8 per cent may be due to impurities in the acid or to lack of accurate published molecular weight data at the experimental conditions. Other pure components were not measured. Molecular weight values available in the literature were extrapolated to the pressure range used in this study (Fig. 2).

Binary Mixtures of the Components (excluding acetic acid). Mixtures studied included two compositions of ethyl acetate and water (Runs VII and VIII) and one mixture of ethyl alcohol and water (Run IX). Results, as illustrated by Fig. 3, in general fell below the theoretical curve. This cannot be explained as a deviation from ideality (association) because such association would approach zero as zero pressure was approached, and the experimental and theoretical curves would have the same intercept. The deviation was particularly marked in Run VII, and was traced to water impurity mainly from the ethyl acetate used. Purification of the ethyl acetate improved the results markedly, though even the results of Run VIII fall below the theoretical value by 4.3 per cent. About 0.002 grams of unaccounted for water would suffice to explain this discrepancy, because of the low molecular weight of water. It was concluded that the experimental technique used, involving some exposure of fluids to the atmosphere, and admission of samples to a dry-ice-cooled burette (to minimize vaporization loss) might very well result in contamination to the extent found (1 to 4.3 per cent). Correction of the results for this trace of water by means of intercept adjustment allowed comparison of theoretical and actual values of molecular weight. The straightness of the lines, as in Fig. 3, is a measure of the ideality of the system. Similar results were obtained for the corrected ethyl acetate-water run. On this basis, the third possible binary mixture, ethyl acetate-ethyl alcohol, was also assumed to be ideal, since water is the most polar of the three molecules.

Binary Mixtures with Acetic Acid as One of the Components. Run III, 85 per cent acid, 15 per cent water, showed excellent agreement between the ideal curves and the experimental points. For Run IV (Fig. 4), 50 per cent acid, 50 per cent water, agreement with the ideal curves was not so good as in Run III, but the same trend of the experimental data can be noted of increasing molecular weight, relative to the ideal curves, as the temperature is lowered. This is attributed to slight association between acetic acid and water, as will be discussed later.

For Run VI (Fig. 5), 50 per cent acid, 50 per cent alcohol, the same conclusions apply. With this

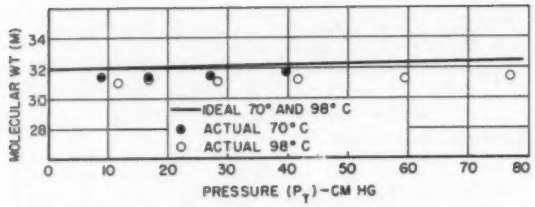


FIG. 3. VARIATIONS OF MOLECULAR WEIGHT WITH PRESSURE
Run IX: 50% alcohol, 50% water

mixture there is a possibility of a reaction occurring. Although the number of stoichiometric moles would remain constant during the esterification reaction, the moles of acetic acid, the associating component, would decrease. By this means possible reaction can be tested, though if reaction occurred it would be almost impossible to interpret the data. Points on Table II marked with * were taken one-half hour after the other points; they showed no evidence of reaction. Similar results were obtained in Run V, 50 per cent acid, 50 per cent ethyl acetate.

In each of these binary mixtures of acetic acid and another component, the deviation from monomer structure of acetic acid is clearly evident in the curvature of the lines. This was satisfactorily taken into account, as explained previously, by evaluating acetic acid molecular weight at its *partial* pressure.

Equimolar Mixture of All Four Components. When it became evident that deviations of the binary mixtures from the ideal situation were small, a last run (Run X, Fig. 6) was made to verify these results for all four components mixed together. When the data were plotted, a curve similar to the previous results was obtained. The constant deviation was large, perhaps owing to errors occurring in mixing of the four components, measuring the density with a hydrometer, and the persistent water contamination.

The results indicate that, while acetic acid associates as if it were alone, a pure component at its partial pressure, the other polar vapors have little effect except to dilute the acid. Except for one observation, erroneous because of condensation (Point II, Run V), the maximum deviation from the ideal curve is found to be 3.5 per cent. Since it was shown[8] that there was a 2.5 per cent possible error inherent in the determinations, a 3.5 per cent deviation represents a relatively minor, and possibly questionable, degree of association between species of molecules.

A possible cause for the positive deviations at 70° C, especially the changing of the deviations from negative to positive in some cases, may be due to the inadequacy of the data for acetic acid at that temperature. The lowest pressure Ritter and Simons[11] investigated was 4.45 cm Hg. In calculating M_0, partial pressures less than half that amount were needed.

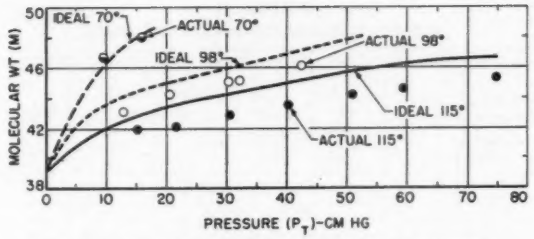


FIG. 4. VARIATIONS OF MOLECULAR WEIGHT WITH PRESSURE
Run IV: 50% acid, 50% water

For binary acetic acid mixtures the average deviation for each run at each temperature is shown in Table III. There is a definite trend from negative to positive deviations as the temperature is lowered. The trend is much more noticeable between the 115° C runs and the 70° C runs. This is probably due to the small temperature difference between 115° C and 98° C. It may indicate, however, that any unusual association occurs only below 98° C.

A comparison, such as that used in Table III eliminates errors of sample size and composition, estimated at 1.5 per cent. Only the estimated 1 per cent error due to occlusion, etc., need be considered. The difference between the 70° C and the 115° C average deviations is over 2 per cent in every case, except for Run III which is not really comparable because it is 85 per cent acid instead of the usual 50 per cent. This deviation, double that which can be attributed to the apparatus, can hardly be ignored. One must conclude that very probably there are interactions between the other polar vapors and acetic acid. They are probably dipole interactions, or perhaps even hydrogen bonding, but in view of their small magnitude and lack of precision, it would be futile to attempt to use these deviations to postulate actual distinct co-polymers.

Why does acetic acid prefer to associate with itself? This is probably due to the double hydrogen bonding available between two acid molecules, giving a heat of dimerization about double that expected with any of the other possible combinations present.

Conclusions

It may be concluded that the polar vapors, ethyl alcohol, ethyl acetate, and water do not associate or interact with each other to a noticeable extent at temperatures from 70 to 115° C and pressures below 1 atmosphere. Acetic acid seems to interact to a small extent with water, ethyl acetate, and ethyl alcohol. These interactions are not great enough to postulate the actual polymers which may be formed.

Calculations of the reaction equilibrium constant for the formation of ethyl acetate from ethyl alcohol and acetic acid may therefore safely be made, allowing only for the assocation of acetic acid with itself.

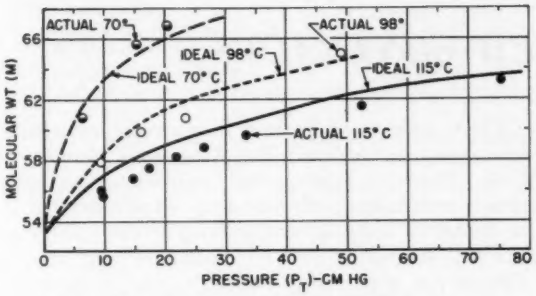


FIG. 5. VARIATIONS OF MOLECULAR WEIGHT WITH PRESSURE
Run VI: 50% acid, 50% alcohol

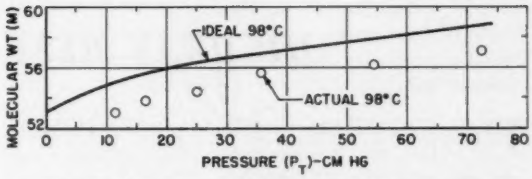


FIG. 6. VARIATIONS OF MOLECULAR WEIGHT WITH PRESSURE
Run X: 25% acid, 25% acetate, 25% water, 25% alcohol

NOTATION

d	arithmetic deviation (%)
E	molecule E
F	molecule F
K_p	partial pressure equilibrium constant
M	molecular weight
M_T	ideal molecular weight
P	pressure (cm Hg)
P_T	total pressure (cm Hg)
R	gas constant (6236 cm Hg cm³/°K mol)
T	absolute temperature (°K)
V	volume (cm³)
W	weight of liquid sample (grams)
w	weight fraction
Y	mol fraction
α	degree of dissociation
i	component i
0	zero pressure

ACKNOWLEDGMENTS

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WATER VAPOR TRANSMISSION THROUGH BUILDING MATERIALS

(Continued from page 8)

extensive series of vapor transmission tests of various materials has not yet been programmed. This facility would appear to be particularly adapted to testing vapor transmission through built-up sections composed of several materials. Also, after further refinements in construction and instrumentation, it would seem suitable for measuring vapor transmission through very low permeance materials, and for the simultaneous measurement of thermal conductance and water vapor permeance,

Of great importance with this method of testing is the ability to measure accurately very small weight changes within a vapor-proof enclosure without having windows or mechanical linkages extending through the seal. Measurements may be taken continuously, instead of manually at given time intervals; thus they can be recorded automatically if a direct plot of weight of moisture versus time is desired as the test progresses.

Two other larger and more elaborate test facilities, designed on similar principles, are in operation at the National Bureau of Standards,[3] Washington, D. C. and at the U.S. Naval Civil Engineering Research and Evaluation Laboratory,[4] Port Hueneme, California. These two facilities are specifically designed for the testing of large built-up wall sections.

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HIGHWAY RESEARCH CONTRACTS

THE FEDERAL BUREAU OF PUBLIC ROADS, the Washington State Highway Commission, and the Washington State Legislature's Joint Fact-Finding Committee on Highways, Streets and Bridges, are the several sponsors of a half-dozen separate studies in various areas of highway research at the University of Washington. The range of subject matter is illustrated by the titles of the new projects:

1. Value of Transport Benefits Resulting from Road Improvement
2. City-County-State Highway and Street Needs in Washington
3. Vehicular Safety and Administration Studies
4. Federal Interest in Forest Highways
5. Highway Economic Impact Manual
6. Pattern of Land Use at Freeway Interchanges

The study of transport benefits is described by the Bureau of Public Roads as basic research relating to time and fuel consumption of certain motor vehicle types under varying operating conditions. It involves the rental of twelve large trucks and buses for a considerable period of time.

Although many problems related to highway planning and taxation are concerned with fuel consumption, there has been little basic research accomplished in this field. Some such work was done on the Pennsylvania turnpike ten or twelve years ago and these data have been supplemented from time to time by studies of minor scope in several states. During 1958 a sizable effort was made to collect fuel statistics in connection with the new federal highway program. These fuel research studies, which were undertaken in several states in the East as well as at the University of Washington, were financed with Bureau of Public Roads administrative funds.

Additional fuel consumption and time studies are now needed in connection with the differential road-user benefits phase of the Highway Cost Allocation Study (Section 210). The data are needed especially in regard to large western-type trailer combinations not normally found in the East, and the data most urgently needed about these vehicles are: (1) fuel consumption and time required to make a stop from a given speed and to return to the given speed, (2) fuel consumption and time required to make a slow-down from a given speed and to return to the given speed, (3) fuel consumption at idling speeds, and (4) fuel consumption and time required to ascend and descend various degrees of grade, and fuel consumption and time required to travel on different kinds of curves.

The transport benefit study is under the immediate supervision of Professor Roy B. Sawhill. Professor J. C. Firey is advising on instrumentation and vehicle certification. Professor H. M. Chittenden is in charge of locating and surveying the road test sections. Professors D. E. Alexander and W. C. Kieling are supervising the collection of data on vehicle performance. Mr. D. Crumbley is concerned with matters of vehicle procurement and loading. Two contracts are involved, one with the federal government and one with the Washington State Highway Commission.

Another study dealing with highway needs is a cooperative effort made in conjunction with personnel of Washington State University under the leadership of G. A. Riedesel, head of highway research in the Division of Industrial Research. The University of Washington will participate in this study mainly through an evaluation of street needs for the cities of Seattle, Tacoma, and Spokane. Professor Martin Ekse will direct this phase of the study with the aid of Professors R. H. Meese, J. E. Colcord, and W. B. Bonow. Statewide aid in the preparation of land-use maps by cities and counties will be provided by Professor E. M. Horwood, guided by population forecasts from the Office of Population Research.

The immediate occasion for this study is the need of additional funds for street and highway construction and maintenance by the cities, counties, and the state to satisfy the requests of the public. The objectives of this study are as follows:

1) To make a physical appraisal of all streets and highways in the state and a determination of the funds needed to bring and maintain all streets and highways into a safe and tolerable condition.
2) To make a study of funds available to the cities, counties, and state from present sources of revenue.
3) To adopt a rational and practical schedule of allocation of street and highway costs to existing and proposed sources of revenue (beneficiaries). This should be based on the findings of the study of Washington State University.
4) To determine the deficiencies between the funds available under (2) and the allocated estimated future costs determined under (1) and (3).
5) To determine the best solution for overcoming the discrepancies between funds available and *allocated* costs shown in (4).

The 1959 Legislature directed its Interim Highway Committee to study also several aspects of the general problem of controlling motor vehicle operation so as to reduce the frequency of accidents. Research of this nature has been assigned to the University of Washington under three headings:

1) Continuation of the work on *Motor Vehicle Administration in Washington in 1958* reported by Professor E. J. Brown. In carrying on this work, answers will be sought for the questions:
   a) What is the dollar cost of traffic accidents in the State?
   b) What is the cost of motor vehicle administration functions in representative comparable states?
2) A study of policies and procedures of motor vehicle licensing in the State. The study should furnish to the State analyses of methods along the following lines:
   a) Promoting more effective enforcement of present regulations
   b) Enforcing full collection of revenues
   c) Securing added efficiency in operations
   d) Increasing public convenience
3) Identification of the comparatively small group of motor vehicle operators who have contributed disproportionately to the growing total of accidents and deaths of the highways. Evidence is accumulating that members of this group can be identified in some cases before they have committed the acts that make them objects of special concern. The predictability of their behavior suggests that perhaps their opportunities to do harm can be restricted and their propensities to become safety problems can be corrected.

   It is proposed to conduct a comparative and analytical study of present methods for identifying and controlling hazardous drivers. The goal of this survey would be to critically evaluate the devices that have been suggested as having productive value, to consider their applicability to conditions in the state of Washington and to suggest administrative and judicial measures for their implementation that would remove dangerous drivers from the highways, or restrict their activities.

Working with Professor Brown on these studies are Professors Wagner, Hardner, Little, Grathwohl, Boore, and Eastman, of the College of Business Administration.

As a part of the enlarged federal highway program, the needs of forest highways have been reappraised by federal and state agencies. The great gap between the estimated needs and the amounts customarily appropriated for forest highways in the past created new interest for critical analysis of the nature of the federal interest in such roads. At the request of the Bureau of Public Roads and the Washington Highway Commission, Professor R. G. Hennes is studying the involvement of federal interest in the forest highways and any consequent implications regarding the distribution of responsibility and sharing the costs of these roads, the growing needs of the system, and the inadequacy of present financing to meet these needs.

The first section of the study involves the establishment, historical development, financing, basic policy and objectives of the federal forest highway system.

Then it reviews the history of the system in Washington, land-transportation routes in the state's National Forests, pressure for road additions and improvement, and the need for an expanded program.

The third section of the study will contain information as to the extent to which needs estimates fulfill the objectives of established federal policy, the involvement of federal interest in forest road improvement, the highways' importance in relation to national defense, conservation of resources and the development of the surrounding areas.

Professor George Stenzel will consider the system as related to forest management.

Also to be studied are the benefits of the system in through and local communication, maintenance of governmental functions, recreation, employment, and reduction in vehicular operating costs.

The benefit-cost ratio concerning increased expenditure on the forest highways will also be discussed in the study, as applied to typical forest roads in Washington, as will the status of state and local highway finance potential.

The justification for increased federal participation will be discussed in three sections. The first is on grounds of equity, the second on grounds of economic justification, and the third on grounds of social and economic expediency.

The final section of the study will apply the findings of the study in terms of legislative alternatives, applying existing and other possible formulas to the various levels of expenditure indicated by the needs studies.

As an outgrowth of the land economic studies undertaken as part of the program of highway research at the University, federal and state authorities became interested in obtaining a published record of the procedures used in these analyses of the effects of highway improvements and bypasses on real estate values and business activity. Consequently, Professor W. L. Garrison is preparing such a manual. The results of the research had been previously published in his earlier report, *Geographic Impact of Highway Improvement*, written in collaboration with Professor Marion E. Marts.

The study of land use development and control at freeway interchanges results from growing concern over the development of commercial land use at the approaches which may render many approach roads obsolete in a few years unless a proper balance is achieved between design standards of such roads and the pattern of land development. This study will be carried on by Professors E. M. Horwood and W. L. Garrison.

The most recent project is a study to determine the land uses competing for approach road sites, the congestion occasioned by these land uses, the adequacy of present land controls at freeway approaches, and future needs and possibilities for the exercise of control over land use development on approach roads through police powers and by other measures.

R. G. Hennes
Professor of Civil Engineering

(Continued from page 15)

Unfortunately, the method used by Graham and Walles is too long and involved to be described here. However, they concluded that the concept embodied in ϕ is as good as the data and that the theory coordinates creep and hot-fatigue data to within the scatter.

Monkman and Grant Method

In 1956 Monkman and Grant[31] presented an empirical relationship between minimum creep rate r_m and rupture life t_r. Almost at the same time, Machlin[32] derived an expression similar to that of Monkman and Grant by analytically relating the rupture phenomenon to a vacancy condensation process.

The relationship may be written

$$\log t_r + m \log r_m = c\,, \qquad (29)$$

where m and c are constants of the order of magnitude unity when the rate is given in per cent per hour, and the life in hours. Since m was found consistently close to one, they proposed a simplified formula,

$$t_r \times r_m = \text{const.} \qquad (30)$$

Some of the main shortcomings of the method were pointed out during the discussion of the original paper, notably the fact that, for some families of materials, contrary to the authors' conclusions, the data did not fall on a narrow band in a log r_m versus log t_r plot but were widely scattered. On the other hand, for individual alloys the correlation was quite fair. The way this method can be used is so evident that it will not be discussed here.

The authors and those who discussed the paper were all in agreement that their method will permit some short cuts in long-time creep and creep-rupture testing, and will allow the evaluation of individual test results, serving as a guide post rather than as an extrapolation method.

Underwood's Method

Underwood[33] has proposed a new method which does not introduce a new concept but a new experimental approach. By comparison of hot tensile strength and rupture data with hot hardness data, he found that there is a linear relationship if one type of data is plotted against the other in a log-log plot, as shown in Fig. 6. Since hot hardness is also a time-dependent function, it can be correlated by most of the parameters, which Underwood illustrates by using the *LM* parameter. Furthermore, he proves for some alloys that there is a unique value of *LM* for any pair of tensile strength-hot hardness defined

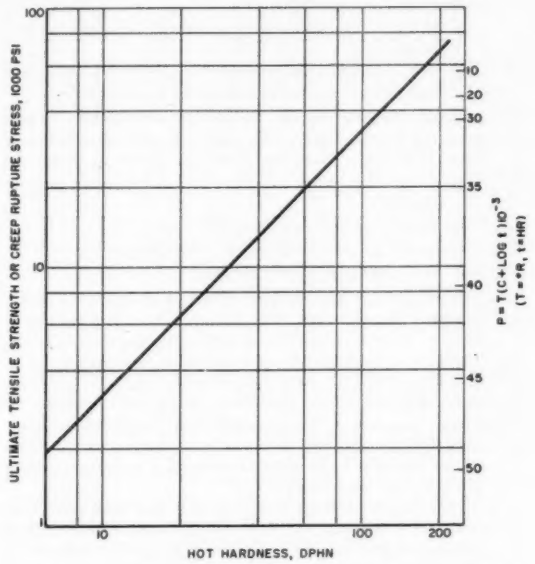

FIG. 6. EXAMPLE OF UNDERWOOD MASTER CURVE

by points of the straight line of Fig. 6. The right-hand vertical axis gives the values of the *LM* parameter. Underwood concludes that "a master curve can be determined for any alloy by running a few ultimate tensile strength tests, a hardness test, and two or three short creep tests. Then, within the limits of validity of the time-temperature parameter, the short hot hardness test can indicate creep rupture stress or tensile strength."

Discussion of Time-Temperature Parameters

We have reviewed some of the best known time-temperature parameters. The principles they embody have been outlined and some information has been given on how to obtain and how to use them. This type of approach was chosen in order to promote better comprehension of the criticisms to which the parameters have been subjected.

There are two general types of methods. Those of one type do not go beyond the establishment of a graphical relationship between stress and a parameter function of time and temperature. The other methods, like the one by Graham and Walles, establish an analytical relationship between those variables and also, in some instances, strain. The criticisms that can be formulated are, however, common to all.

From a fundamental standpoint, all the methods implicitly assume the existence of an equation of

state that controls the mechanical behavior of materials. This is a correct approach so long as there is full realization of the kind and number of variables and adjustable constants that should be related by such an equation. Quite conclusive evidence now indicates that the mechanical behavior of materials does not follow any simple equation of state[34,35,36] and that the number of variables should not be less than five:[37] stress, strain, time, temperature, and one as yet undefined that accounts for the structural changes of the materials. This last variable is frequently overlooked and explains many of the disagreements between theory and experiments. Bailey[38] pointed out this problem when he recommended the inclusion of a thermal-action effect to better correlate data from long- and short-time tests; his theory is based on the fact that the structural changes, and hence the material responses, should vary with different exposures to temperatures.

The number of necessary adjustable constants is another problem which has not yet received the needed attention. Except for the work of Graham and Walles,[30] little else has been done in this field. Of 75 sets of data they fully analyzed they found that the numbers of freely adjustable constants necessary to correlate the data within limits statistically determined from the scatter of the original data, are those given in Table I.

Those numbers of adjustable constants were obtained using stress, time or creep rate, and temperature as independent variables. Although by somewhat different and more rigorous analysis involving structure-dependent variables, the number of constants freely adjustable may differ from those given in Table I, the data presented give a clear indication of the type of objections to which the methods discussed may be subjected.

Larson-Miller's, Dorn's, Manson's and Graham and Walles' methods are the only ones which have been subjected to comparative studies.[3,25,26] Manson's method has been consistently found to give better correlation and predictions than the others. The advantage of this method can now be traced to the fact that it is the only one that involves two freely adjustable constants, log t_a and T_a. Though Graham's ϕ also includes two variables A and T', A is generally taken as 20. Some comparisons made by Graham and Walles[30] using different values of A for different materials and testing conditions have proved the importance of a greater number of adjustable constants. It is, of course, understood that they must be kept to a required minimum: otherwise the method loses generality.

TABLE I

Number of Free Constants	Number of Sets of Data Correlated
2	12
3	4
4	39
5	7
6	10
7	1
8	2

Another point that should be emphasized is the fact that, until a rational theory is developed that proves to have universal value, creep will remain a phenomenon of statistical nature. Those who are familiar with creep-testing techniques and results realize that the data presently available constitute too small a sample, statistically. The problem is worsened by the fact that most of the data are of the stress-rupture type which is now of very little use in solving the problems of today's technology.

For heated-structures designers, none of the methods is of any value since all of them were developed from uniaxial loading data. The high-temperature behavior of materials under combined stresses is very little understood.

Until the general problems outlined above are clarified, it is impractical to discuss and analyze contingent details.

On the other hand, parametric procedures have found their way because they provide for a more systematic comparison of data; and owing to their ability to coordinate data they allow compilation and presentation of a large amount of data in a simple form. They can also be used for some limited predictions, provided the user is fully aware of the limitations of the methods and the reliability of the data used in preparing the master curves.

Though many things are yet to be learned about creep it is of marked significance that materials of structures, so varied as pitch and metals, exhibit behavior so similar.

Conclusions

Parametric procedures are yet in an embryonic stage. A rational theory to explain the high-temperature mechanical behavior of materials is still lacking. Present creep data constitute too small a sample to provide a firm basis for such a theory. Parametric methods can be used for correlation, presentation, and comparison of data. Limited extrapolations can be made if the limitations of the methods are accounted for and the basic data are reliable.

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PATTERN RECOGNITION IN AN ELECTRONIC READER

(Continued from page 21)

The horizontal scan recognition logic was based to a certain extent on human visual principles. Instead of using a point-by-point scan of each letter, an attempt was made to develop a recognition technique based on sensing only the most obvious characteristics of each letter. This approach was shown to be feasible by the results obtained. In reference to the particular recognition technique, however, six of the 32 Russian letters were not uniquely identified. This implies that another specific recognition coding method might be examined for complete definition. Such a study is currently in progress in the Electrical Engineering Department under Engineering Experiment Station sponsorship.

An important feature of the horizontal scan is that the reader can generate scan information and process it on a parallel basis. Because of this feature a single pass of the scan spots over the letter was sufficient for identification. This fact permits recognition at roughly five times the rate possible with serial scanning. Parallel or simultaneous techniques can certainly be applied to practical electronic reading devices.

Hill Appointed Associate Dean of the Engineering College

W. RYLAND HILL, Professor of Electrical Engineering, has been appointed Associate Dean to assist Dean Harold E. Wessman in the administration of the College of Engineering. In the past four years, enrollment in the College has increased by nearly 500 undergraduate students, and graduate enrollment has more than doubled. During the past school year more than 2,800 undergraduates and graduate students were enrolled.

Professor Hill is an alumnus of the University (1934) and has been a member of the Electrical Engineering Department faculty since 1941. His textbook, *Electronics in Engineering*, which was published by McGraw-Hill in 1949, is being revised for a new edition.

During 1957-1958 Professor Hill was on leave from the University to act as Head of the Faculty of Electronics at the Madras (India) Institute of Technology, under the Technical Cooperation Mission of the U. S. Department of State.

The new associate dean will continue to teach on a part-time basis after assuming his administrative duties in September.

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